NOTE

This Microfiche meets the quality requirements of the American National Standard for Microfiche of Documents (ANSI PH5.9-1975). However, because of imperfections in the document from which it was made, it contains images that are illegible or difficult to read. The source document for this microfiche is the best copy that could be obtained prior to filming.

CIS Congressional Information Service, Inc
Washington, D.C.

PB85-218345

Preventing Illness and Injury in the Workplace

VOL. II—PART C: WORKING PAPERS

#14—Potential Office Hazards and Controls
#15—Carpal Tunnel Syndrome: A Case Study
#16—Implementation of the Occupational Lead Exposure Standard
#17—Technologies for Controlling Worker Exposure to Silica
#18—Compliance With the OSHA Cotton Dust Rule: The Role of Productivity Improving Technology

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D. C. 20510

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

J952-76

PB85-218345

Preventing Illness and Injury in the Workplace
Volume 2-Part C: Working Papers

Office of Technology Assessment, Washington, DC

Sep 84

U.S. Department of Commerce
National Technical Information Service
NTIS

J952-76

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No. PB85 218345/AS

4. Title and Subtitle

Preventing Illness and Injury in the Workplace
Volume II-Part C :Working Papers

5. Report Date

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Same as box 12.

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

Office of Technology Assessment
U.S. Congress
Washington, D.C. 20510

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This volume is one three volumes of working papers prepared as background information for OTA's assessment: Preventing Illness and Injury in the Workplace.

17. Document Analysis a. Descriptors

safety
prevention
hazards
environmental engineering
office management
regulations
government policies
standards

b. Identifiers/Open-Ended Terms

Occupational Safety and Health Administration
health standards
technology assessment

c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages 632

22. Price

(See ANSI–Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

PREFACE

This volume consists of working papers prepared for the OTA assessment Preventing Illness and Injury in the Workplace. These working papers have not been reviewed or approved by the Technology Assessment Board.

Preventing Illness and Injury in the Workplace

Volume II — Working Papers

PART C:

#14 — Arndt, R. and Chapman, L., Potential Office Hazards and Controls, contract report, September 1984.

#15 — Bleecker, M., Carpal Tunnel Syndrome: A Case Study, contract report, May 1984.

#16 — Goble, R., Hattis, D., Ballew, M., Thurston, D., Implementation of the Occupational Lead Exposure Standard, contract report, November 1983.

#17 — Hickey, J. L. S., Rice, C. H., Boehlecke, B. A., Technologies for Controlling Worker Exposure to Silica, contract report, August 1983.

#18 — Ruttenberg, R., Compliance with the OSHA Cotton Dust Rule: The Role of Productivity Improving Technology, contract report, March 1983.

POTENTIAL OFFICE HAZARDS AND CONTROLS

SEPTEMBER 1984

THIS CONTRACTOR REPORT WAS PREPARED AS BACKGROUND INFORMATION FOR OTA'S ONGOING ASSESSMENT: PREVENTING ILLNESS AND INJURY IN THE WORKPLACE. AS A CONTRACTOR'S REPORT TO OTA, THIS REPORT HAS BEEN NEITHER REVIEWED NOR APPROVED BY THE TECHNOLOGY ASSESSMENT BOARD.

Prepared by:

Robert Arndt, Ph.D.
Larry Chapman, M.S.
Department of Preventive Medicine
University of Wisconsin
Madison Wisconsin

For:

Office of Technology Assessment
Congress of the United States of America

For additional information contact Robert Arndt at 608-263-6717

Preface

This volume is a paper, "Potential Office Hazards and Controls," written for OTA to assist in preparation of the report Preventing Illness and Injury in the Workplace. Findings and conclusions made by the authors of the paper, Robert Arndt, Ph.D. and Larry Chapman, M.S., Department of Preventive Medicine, University of Wisconsin, Madison, Wisconsin, are theirs and not necessarily OTA's. This paper may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and it is being made available for such purposes.

This paper discusses office worker exposure to: indoor air pollution in tightly insulated buildings; potentially harmful psychological stress from poorly designed jobs; and potentially harmful physical stress from poorly designed machines and work stations. While these problems are non-life threatening or shortening, some are potentially disabling, often cause unnecessary discomfort, and can be excessively costly in terms of lost work-days. Various controls for these hazards are considered and evaluated.

This study, together with research in other areas was used in preparation of OTA's assessment report, to be delivered to Congress early in the winter of 1984-1985. In addition, other related OTA assessment are underway: Information and Communication Technologies in the Office, Reproductive Hazards in the Workplace, and Technology and Structural Unemployment: Retraining Adult Displaced Workers. Additional information on tightly insulated buildings may be found in the OTA reports, Energy Efficiency of Buildings in Cities and Residential Energy Conservation.

ACKNOWLEDGEMENT

The authors would like to thank Ms. Michele Miller for her typing and editorial assistance in the preparation of this report.

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY i

LIST OF TABLES vii

LIST OF FIGURES ix

1 INTRODUCTION 1

Background 1

Office Work in the United States 2

Professional and Technical Workers 3

Managers and Administrators 5

Sales Workers 7

Clerical Workers 7

Employment Projections and Shifts 9

Growth Rates 9

Occupations 11

Age Distribution 11

Sex Distribution 13

Office Work and New Technology 16

Motivating Forces in the Application of New Office Technologies 17

Potential Effects of Office Automation 18

The Impact of the Video Display Terminal 22

Microelectronics Applications 23

2 POTENTIAL OFFICE HAZARDS 26

Introduction 26

PAGE

- Summary 28
- Stress 29
- Effects of Automation 32
- Controlling Workplace Stress 36
- Obstacles to Implementation of Control Strategies . . . 39
- Developing a Public Policy 41

Ergonomic Problems 41

- Musculoskeletal Problems 42
- Visual Problems 52
- Job Demands 61
- Summary 64

Temperature 66

Humidity 71

Air Quality 73

- Number of Office Workers at Risk 74
- Severity of Exposures 77
- Health Consequences 78
- Sources of Air Pollution in Offices 79
- Control Strategies 80
- Application of Control Strategies 81
- Research Needs 83
- Economic Considerations 84

Noise 85

Accidents and Injuries 89

- Accident Types 89
- Nature of Injuries 92
- Estimation of Injury Rates 92

PAGE

Causes of Accidents 96

Control of Safety Hazards 96

Radiation 97

Overview 97

Radiation Measurements 100

Radiation and Fears of Adverse Health Effects 102

Control Technologies 105

3 RELATED TOPICS 110

Concerns and Activities of Interest Groups 110

Employee Interests 110

Employers 112

Manufacturers 112

Government 114

International Activities 115

Standards Activities Related to Office Hazards 117

Relationship Between Office and Non-office Hazards 119

4 STRATEGIES FOR CONTROLLING HAZARDS 121

Alternate Strategies for Implementing Office Hazard Controls 126

Regulatory Activities 126

Generation, Dissemination and Utilization of Knowledge . 131

Market Incentives and Controls 141

Manpower Development 147

Methods of Overcoming Control Strategy Obstacles 156

Summary 159

REFERENCES 161

EXECUTIVE SUMMARY

Office workers are expressing more and more concern over potential and perceived hazards including stress, air quality, ergonomic problems, temperature, noise, and radiation. Worker advocacy groups, labor unions and the popular press have been responsible for much of this increased level of awareness concerning potential office hazards.

The increasing numbers of complaints about musculoskeletal and visual problems and stress have forced many employers to seek methods for controlling office hazards. The introduction of new office technologies, in particular the video display terminal (VDT), is probably responsible more than anything else, for the increased attention given to office hazards.

1. Addressing the present concerns of office workers requires the acceptance of a broad definition of occupational health and safety which recognizes as hazards, not only those conditions which can cause physical impairment, but also those which can have an adverse effect upon mental and physical well-being.
2. A review of existing research indicates that there is very little data available which can be used to accurately assess either the number of individuals exposed to various alleged hazards or the adverse health effects of actual exposures. Much of the available information is based upon anecdotal observations or case studies at specific worksites. While more research is available related to the use of VDTs than any other type of office work, even this data is of somewhat limited value due to methodological problems inherent in certain studies. Assessment of risk is further complicated by the lack of objective information concerning exposures levels.

Subjective reports from individuals must generally be relied upon. Many studies do not distinguish between exposure and effects. Finally, the nature of many of the adverse outcomes are not easily measurable. Most complaints of health effects do not lend themselves easily to medical assessment, and consequently, self-reported symptoms are the only source of data. There are few studies available which relate long term low-level office exposures to adverse health effects.

3. Intensive visual demands involved in many office jobs have given rise to frequent complaints of discomfort, fatigue, irritation and strain. In many cases, failure to give adequate attention to correct lighting conditions has exacerbated visual problems. Problems seem to be greater in jobs involving the use of VDTs. Poor quality displays in some cases, and lack of consideration of special lighting requirements for VDTs in others, are likely causes of the higher incidence of problems in many VDT jobs.

4. Repetitive tasks, constrained working positions, inadequate rest, and poorly designed workstations and chairs have led to a variety of musculoskeletal complaints. While some studies have sugg[illegible]ed that these problems are more frequent among VDT operators, it appears that job demands and working positions are more important than whether a VDT is being used. The higher frequency of complaints observed in some cases among VDT operators may be due in part to the fact that VDT jobs in many cases tend to be more repetitive.

5. Improper ventilation in offices has made complaints about stuffy offices commonplace. There has also been an increasing number of

episodes of acute affects due to air contaminants such as microorganisms, gases, vapors and dusts. While there is a lack of data available concerning the number of people exposed to poor air quality, studies have indicated that exposure levels are generally low. At the same time, it is evident that very low exposure levels are capable of producing complaints and adverse health effects. Allergic responses, sensitization and synergistic effects may account for some of the acute responses which have been observed in certain cases. The effects of long term low-level exposures are in many cases unknown. Energy conservation measures, including sealing of buildings and reductions in ventilation, have exacerbated problems in some cases.

6. Complaints concerning improper temperature are probably the most common of any heard from office workers. At the same time, there is no evidence to indicate that the expressed discomfort is associated with any serious health effects. Thus, temperature complaints must be considered primarily as a source of discomfort or possibly as a source of stress. Some of these problems may be traced directly to conscious efforts to conserve energy and can thereby be attributed to policy decisions. At the same time, it is evident that many problems are due to heating and ventilation systems which do not perform adequately; or a variety of other factors which are generally not given adequate consideration including thermal effects of windows, equipment, and air movement.

7. Noise problems in offices are seldom of sufficient magnitude to constitute a hearing loss risk. Generally office noise acts as a source of irritation, discomfort or distraction, with conversation

being one of the most common sources. In some cases, certain types of equipment may be responsible for high noise levels which could present a risk of hearing loss, and also serve as an important source of irritation and stress.

8. Reports of cataracts and clusters of reproductive problems among VDT operators have generated fear that VDTs emit harmful levels of radiation. There is, however, no scientific evidence currently available which specifically links either of these problems with VDTs, although very few studies have actually addressed the issue. Radiation emissions have consistently been found to be below applicable safety standards. Despite assurances by industry and the federal government, concern continues to be raised, however, since there are no existing standards for some regions of the non-ionizing electromagnetic spectrum within which VDT emissions occur. There also exists the fear that current safety standards may not provide sufficient protection. Whether or not there is a hazard, it is clearly evident that a high level of concern and fear exists among VDT operators, especially those who are pregnant.

9. A variety of working conditions including environmental, job design, organizational and psychosocial factors have been identified as potential sources of stress in offices. While the relationship between stress and disease is generally accepted, there are few studies which have demonstrated physical outcomes of long term exposure to stressful working conditions in offices. Most stress-related complaints are reflected in attitudinal and emotional feelings about work, or self-reported psychosomatic problems. Stressful working conditions may also contribute to increased job dissatisfaction, absenteeism and turnover.

10. Several of the hazards which may be present in office work have the potential to cause serious physical harm, especially when exposures are repeated and long term. The majority of complaints, however, concern immediate effects in the form of discomfort, irritation, pain, dissatisfaction and emotional responses beyond what might be expected in a normal workplace. Chronic exposure leads to a deterioration of general health and well-being. It is clear that any public policy or strategy for controlling office hazards must address these complaints as well as more serious impairments.

11. Control methods exist for all of the recognized office hazards, but are not applied for a number of reasons. In some cases, the failure to abate hazards can be attributed to a lack of knowledge (concerning both causes and controls) among those responsible for making decisions including managers, manufacturers, and professionals. In other cases, problems persist because there is no incentive to make changes. Discomfort, pain, irritation and dissatisfaction generally cannot be evaluated in terms of direct costs to employers and control methods often appear financially counter productive. Furthermore, the economic costs of absenteeism, turnover and reduced performance which might be associated with poor working conditions have not been demonstrated to a sufficient degree to provide an incentive for change. While legislative mandates provide an incentive, many of the hazards associated with office work do not lend themselves easily to such methods. Traditional standards setting approaches do not appear to offer a feasible alternative at this time.

12. There currently exists a definite need to generate information concerning the nature and extent of hazardous exposures in offices. In addition, the efficacy of implementing different abatement methods must be convincingly demonstrated.

13. Dissemination of accurate and usable information and systematic training of employees, employers, and professionals responsible for the design of office environments and office work are obvious necessities under any circumstances, and especially in view of the changes which will continue to occur in office work under the inevitably growing influence of micro-electronic technologies. This may be the most important means by which government can take an immediate and active role in addressing office working conditions.

LIST OF TABLES

TABLE		PAGE
1-1	Occupational classifications of professional and technical workers	6
1-2	Occupational classifications of clerical workers	8
1-3	Estimated number of office workers in the U.S.	10
1-4	Age distribution of U.S. labor force	12
1-5	Numbers and growth rates of women in selected occupations	14
1-6	Estimated percentage of women in the office work force	15
1-7	Typical uses of microcomputers	25
2-1	Advantages and disadvantages of alternate stress control methods	38
2-2	Frequency of reported musculoskeletal problems from various studies	44
2-3	Ergonomic design features addressed by standards and guidelines	47
2-4	Break schedules recommended by various groups	50
2-5	Frequency of reported visual problems reported from various studies	53
2-6	Frequency of reported temperature related problems	68
2-7	Frequency of reported ventilation problems	76
2-8	Examples of types of air contaminant exposures in offices	80
2-9	Self-reported noise problems in offices	86
2-10	Accidents among white collar workers in Wisconsin by type of accident-1982	90
2-11	Accidents among white collar workers in Wisconsin by nature of injury-1982	91
2-12	Estimated injuries by occupational classification for all U.S. workers	93
2-13	Estimated U.S. office worker injuries	95

TABLE		PAGE
2-14	Reported radiation measurement units and locations	109
3-1	Proposed legislation addressing office equipment health and safety	118
4-1	Hazard control in offices	122
4-2	Considerations related to regulation of office hazards	132
4-3	Considerations related to generation, dissemination, and utilization relevant to specific office hazards	135
4-4	Manufacturers' ability to keep pace with end-user needs as seen by the end-user	146
4-5	Problems associated with market-based control strategies	148
4-6	Manpower resources and related problems	153
4-7	Professional society and trade association services	155

LIST OF FIGURES

FIGURE		PAGE
1-1	Estimated numbers of U.S. workers employed primarily in offices	4
2-1	Potential ergonomic risk factors associated with office workstation design	46
2-3	The electromagnetic spectrum--frequency, boundaries, energy sources and designations	99

CHAPTER 1

INTRODUCTION

Background

The office has traditionally been considered as a relatively clean, safe and healthy place to work. Relatively speaking this is supported by data based upon established criteria for measuring health and safety risks, such as accidents, fatalities and occupational diseases. However, the recent concerns being voiced by office workers suggest that different measurement criteria might lead to a different conclusion about the environments and working conditions of office workers. These concerns which are expressed in terms of discomfort, irritation, anxiety, job dissatisfaction and diminished well-being are not reflected to any degree in currently available statistics from organizations such as the National Safety Council or the Bureau of Labor Statistics. More appropriate outcome measures might include sick leave, absenteeism and turnover rates.

The increasing awareness and concern related to health and safety in the office can be attributed to three concurrent public health issues: (1) stress; (2) air pollution; and (3) VDT-related complaints.

The magnitude of concern about stress is reflected in the proliferation of popular press articles, seminars, workshops and stress coping or stress management techniques. The American Academy of Family Physicians estimated that as many as two-thirds of all office visits to physicians are prompted by stress-related symptoms (Time, 1983). A 1977 NIOSH study (Colligan et al., 1977) which reported that secretaries, office managers, and manager-administrators were among the 12 high stress-related disease incidence occupations (out of 130 studied); and the report from The Framingham Heart Study that coronary heart disease rates were almost twice as great among women holding clerical jobs as housewives (Hayres and Feinleib, 1980), have brought the issue of job stress in the office to the forefront.

The general public health concern over air quality, along with energy conservation measures implemented in the late 1970s, have given rise to a variety of questions and complaints about indoor air quality. While a number of episodes of health-related disorders have surfaced, the most frequent complaints relate to the so called "stuffy office syndrome."

Perhaps the single most important underlying influence in raising the health and safety consciousness of office workers has been the introduction of the video display terminal into the office. Early European reports indicated that those who worked at VDTs reported a high incidence of visual, musculo-skeletal and stress related disorders. These health concerns were expanded in the U.S. to include possible radiation effects in the late 1970s when reports of alleged radiation related cataracts and adverse reproductive outcomes began to surface. While the sheer magnitude of the number of workers utilizing VDTs no doubt accounts for much of the widespread concern currently being witnessed, the influence of the public media, organized labor, and public interest groups cannot be denied. This influence is reflected in the fact that legislation concerning the use of VDTs has been proposed in at least eight states.

Office Work in the United States

The office environment has been broadly defined as "the workplace of white collar workers, including managers and administrators, professional and technical personnel, salespersons, and clerical workers" (Saffady, 1981, p. 1). Thus, the terms "white collar worker" and "office worker" are often used interchangeably. For the purpose of this report, it is useful to examine further and distinguish between different types of white collar workers and different uses of offices since some of the subsequent discussion on office automation, risk factors and control techniques is highly dependent upon these distinctions.

According to BLS statistics, approximately 51.4 million of the 102 million member U.S. work force were classified as white collar workers in 1980 (Carey, 1981). (See Figure 1-1 for summary.) The white collar work force was further divided into four categories:

Professional and technical	16.4 million
Managers and administrators	9.4 million
Sales workers	6.8 million
Clerical workers	18.9 million

Examination of occupations within these groups reveals that certain categories can be established based upon the type of office use (e.g. processing information vs. providing services) and the amount of office use (intensive vs. incidental). In other cases, there are significant numbers of white collar workers who do not actually work in offices. The major occupations which can be distinguished on this basis are described below for each of the white-collar categories. Except when indicated, occupational employment figures are based upon U.S. Census Bureau (1983) data.

Professional and Technical Workers

Most offices in this category might be referred to as staff offices. Some serve functions such as planning, accounting and marketing while others

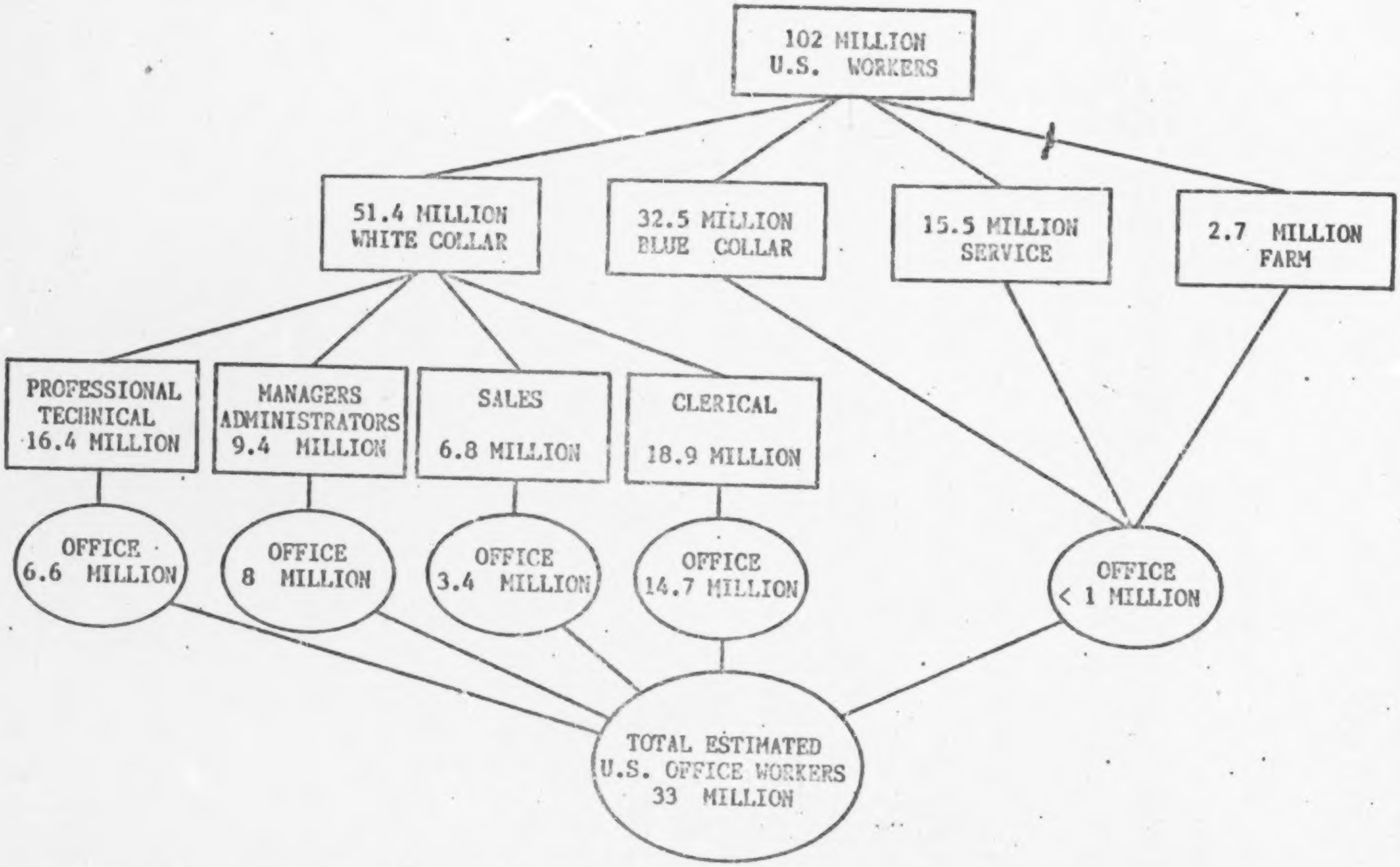

102 MILLION
U.S. WORKERS
51.4 MILLION
WHITE COLLAR
32.5 MILLION
BLUE COLLAR
15.5 MILLION
SERVICE
2.7 MILLION
FARM
PROFESSIONAL
TECHNICAL
16.4 MILLION
MANAGERS
ADMINISTRATORS
9.4 MILLION
SALES
6.8 MILLION
CLERICAL
18.9 MILLION
OFFICE
6.6 MILLION
OFFICE
8 MILLION
OFFICE
3.4 MILLION
OFFICE
14.7 MILLION
OFFICE
< 1 MILLION
TOTAL ESTIMATED
U.S. OFFICE WORKERS
33 MILLION

FIGURE 1-1. Estimated number of U.S. workers who work primarily in offices. (See text for explanation of estimation methods.)

are oriented toward professional categories such as engineering and law (Panko, 1981). Table 1-1 lists the major occupations and their prevalence among the professional and technical category of white collar workers. As can be seen from Table 1-1, a number of office types and uses would have to be grouped together if all these occupations were to be considered simply as office workers. The most notable are health care professionals and technicians which account for 19% of the total. These individuals are primarily performing a service within their offices rather than carrying out information processing similar to a bank or insurance company. The second major category of professionals includes preschool, primary and secondary school teachers and accounts for 19% of the professional-technical work force. While some of these may have offices, their use is incidental to the primary function of their jobs. Other categories of professional workers which include a significant number of varied or limited office uses include writers, artists and entertainers; religious, social and recreational workers; as well as a variety of occupations included in the category listed as "other" (e.g. airline pilots, air traffic controllers, etc.). Based upon these considerations, it is estimated that approximately 40% of the 16.4 million professional and technical workers actually spend a substantial portion of their time in office environments carrying out information related activities.

Managers and Administrators

Most workers in this category work in offices that manage organizational units, often referred to as executive offices. The largest single category of occupations which probably does not make substantial use of a office includes managers of restaurants, cafes, and bars (5-6% of all managers and administrators).

TABLE 1-1

Occupational Classification of Professional and Technical Workers

Occupation	Number Employed (1000)	Percentage of all Professional Technical
Engineers, scientists and engineering technicians	3,303	20
Accountants	1,126	7
Health care (physicians, dentists, nurses, therapists, technicians)	3,125	19
Teachers -		
College and University	585	4
Other	3,197	19
Writers, artists, and entertainers	1,388*	8*
Religious workers, counselors, social and recreational workers	1,036	6
Computer specialists	627	4
Others	2,100	13
TOTAL	16,420	100%

*Includes certain office jobs (e.g. newspaper writers).

A substantial number of managers also hold positions in retail sales. Combined with a variety of other occupations, it is estimated that at least 15% of the workers classified as managers and administrators do not spend a significant amount of time in an office.

Sales Workers

This category of occupations includes sales clerks, peddlers, and traveling salesmen; none of whom work primarily in an office. Sales clerks alone account for 43% of all sales workers. It is, therefore, estimated that a maximum of 50% of all sales workers are actually employed in offices.

Clerical Workers

Table 1-2 lists the major occupations included in the clerical category. Clerical offices deal mostly with the processing of routine information (Panko, 1981). It is this type of office that is most often referred to when the terminology "office worker" is used. Traditional office management courses are generally referring to clerical workers when they discuss office workers, and most standard texts on office administration deal almost exclusively with clerical offices (Keeling et al., 1978).

This category also includes a variety of other occupations which do not fit the traditional concept of a clerical office, however, including telephone operators, bank tellers, dispatchers, etc.

The largest identified occupations unlikely to work in offices include: storekeepers (3%), shipping and receiving clerks (3%), postal employees (3%), counter clerks (2%) and teachers' aides (2%). In addition, a substantial portion of those classified as cashiers (9%) might be included as well as a number of those in the "other" category (e.g. stock clerks, meter readers,

TABLE 1-2

Occupational Classification of Clerical Workers

Occupation	Number Employed (1000)	Percent of Total Clerical Work force
Secretaries	3917	21
Bookkeepers	1961	10
Cashiers	1660	9
Typists	1031	5
Office machine operators	966	5
Office clerks	838	4
Insurance claims	731	4
Receptionists	675	4
Bank tellers	569	3
Storekeepers	528	3
Shipping and receiving clerks	525	3
Mail carriers/postal clerks	511	3
Teachers' aides	400	2
Counter clerks	360	2
Telephone operators	308	2
Clerical supervisors	250	1
Stenographers	74	—
Other (e.g. dispatchers, library assistants, messengers, etc.)	3496	19
TOTAL	18,900	

library assistants, desk clerks). It is, therefore, estimated that approximately 78% of all clerical workers are employed in offices.

It should also be noted that a small number of blue collar workers, service workers and farm workers do work in offices.

It is estimated that approximately 33 million (32%) of those employed in 1980 worked in offices (Panko, 1981, estimated 40% but included certain health care occupations; other estimates have been as low as 20% [Zisman, 1978; Sadleir, 1980]). While some major shifts in occupational categories have been occurring in the 70s and 80s (described below), these would not appreciably affect the applicability of this estimate to 1983 employment. Based upon the above considerations, it is believed that the numbers and percentages of workers in the major occupational categories listed in Table 1-3 provide a reasonable estimate of the number of workers potentially affected by the types of risk factors discussed in this report.

Employment Projections and Shifts

Four factors relating to projected changes in the nature and distribution of the office work force are considered below: growth rates, occupational distributions, sex distribution, and age distribution.

Growth Rates

The labor force is expected to increase by about 17-25% during the 80s (Nardone, 1982). All major occupational groups, except farming, should continue to grow, with the largest gains being registered among service workers and white collar workers.

TABLE 1-3

Estimated Number of Office Workers in the United States

Major categories of workers	Number in work force	Percent of total office workers
White Collar		
Professional, technical	6.6 million	20%
Managers, administrators	8.0 million	24%
Sales workers	3.4 million	10%
Clerical workers	14.7 million	45%
Blue collar, service, farm	.3 million	1%
TOTAL	33 million	

Occupations

The number of professional and technical workers is expected to increase at a rate slightly higher than that for all occupations combined. The largest gains will, however, be in the health-related professions. Sales workers and clerical workers will also increase in numbers slightly above average until 1990. Management and administrative employment is expected to increase at a rate slower than other occupational groups. In terms of new white collar openings through 1990, clerical jobs are projected to increase by the greatest numbers. The introduction of new technology into offices will lead to high growth rates in computer related jobs such as systems analysts, computer operators, programmers and peripheral EDP equipment operators (Carey, 1981; Howard and Rothstein, 1981). There are conflicting opinions, however, about the effects of office automation on clerical workers. Since a major emphasis is increasing productivity, the number of office workers has to decrease or the amount of work accomplished must increase if productivity gains are to be realized. It is generally believed that automation will not substantially affect the number of jobs available to professional and technical workers but may eliminate some middle management positions (Business Week, 1983).

Age Distribution

Substantial shifts in the age distribution of the available work force are expected to occur during the next two decades. Projections are described in Table 1-4 (from Wolfbein, 1982).

The work force of the 80s will undergo a shift toward more experienced workers as more people enter the 25 to 44 age group. This group accounted for 40% of the work force in 1970, 46% in 1980, and will represent over 54% of the work force in 1990. Since middle management is usually drawn from this group,

TABLE 1-4

Age Distribution of U.S. Labor Force*

Age	Percent of Total Work Force 1980	 1990
16-24	23.5	18.5
25-34	26.9	28.6
35-44	19.3	25.5
45-54	16.2	15.8
55-64	11.2	9.1
65+	2.9	2.5

*Based upon Wolfbein, 1982

there should be an increasing availability of qualified individuals and decreased opportunities for career advancement.

The decreased opportunities could be offset to some degree by the reduction of more senior workers, especially over 55 (17.5% in 1970 and 11.6% in 1990). This trend could lead to a greater consciousness of job security (Mills, 1979).

There will also be a reduction in available young workers for entry level jobs. This fact along with a higher educational level and potentially different values among young workers has led some to believe that there may be a labor shortage for entry level jobs, especially if they are simplified, repetitive and boring jobs with little opportunity for advancement (Spencer and Long, 1983).

Sex Distribution

Women now constitute about 43% of the total labor force. This number has grown from 38% in 1972, and is expected to continue to rise in the future. Almost 54% of all white collar workers are women, with the largest proportions occurring in clerical jobs, and the lowest in managerial and administrative jobs. Table 1-5 indicates the percentages of women in selected jobs and the percent increase over 1972 levels. Some of the largest gains for women workers between 1972 and 1981 were realized in the following occupations: accountants, personnel and labor relations, bank officials and finance managers, office managers and clerical supervisors. The estimated percentages of women actually working in offices are listed in Table 1-6. Approximately 53% of all office workers are therefore estimated to be women, with the highest proportion (85%) occurring in clerical work. The proportion of women

TABLE 1-5

Number and Growth Rates of Women in Selected Occupations

Occupation	Percentage of women 1981	Percentage Increase Since 1972
Professional/technical	44.6	5.3
Accountants	38.5	26.8
Computer specialists	27.1	10.3
Engineers	4.4	3.6
Personnel/labor relations	49.9	18.9
College and university professors	35.2	7.2
Technicians	18.8	9.7
Managers/administrators	27.5	9.9
Bank officials and financial managers	37.5	18.5
Health administrators	49.8	3.2
Managers, supervisors	50.9	8.3
Office managers	70.6	28.7
Sales	45.4	3.8
Clerical	80.5	4.9
Bank tellers	93.5	6.0
Bookkeepers	91.1	3.2
Clerical supervisors	70.8	13.0
Office machine operators	73.6	2.2
Secretaries	99.1	—
Stenographers	90.4	5.3
Telephone operators	92.9	3.8
Typists	96.3	—

TABLE 1-6

Estimated Percentage of Women in the Office Work Force

Office occupational groups	% Female
All white collar office jobs	53%
Professional and technical	25%
Manager, administrator	25%
Sales workers	30%
Clerical	85%

in the work force is expected to continue to increase and will account for most of the growth in employment during the 80s.

Office Work and New Technology

The traditional office has been subjected to an accelerating trend toward increasing technological change. This trend toward the electronic storage and transmission of information has led to what is referred to as the "office of the future," the "paperless office" or "office automation." It began with the introduction of the electric typewriter in the mid-sixties. Copiers improved tremendously during this period and offices began utilizing computer assisted microfilm retrieval. While minicomputers had been available for some time, high costs prevented widespread use until the early 70s.

The 1970s saw further advances, especially in the area of word processing. The more widespread use of minicomputers and the introduction of microcomputers in the late 70s led to decentralized uses of computers. Micrographics and reprographics were more extensively tied in with computers. In addition, electronic communications technologies, including electronic mail, voice messaging, teleconferencing, and videoconferencing were introduced. Current office technology is focusing on creating an "electronic workstation" which allows the user to perform all functions previously carried out using paper, and tie individual resources into a single network.

Other technological tools currently being developed or improved include: voice communication devices for recognizing and synthesizing speech, electronic speech compressors, "intelligent telephones," optical character readers, and electronic blackboards. In addition, many of these are being adapted for what is referred to as "telecommuting," by developing a portable office. The rapid development of these technologies can be attributed to the recent advances made in the field of microelectronics.

Motivating Forces in the Application of New Office Technologies

The most often cited motivating force in the application of new technology is the desire to increase productivity. Concerns over the apparent lack of improvement in white collar productivity have led many businesses to invest in office technology. There are two ways in which such tools can be applied in an attempt to accomplish this end: (1) cost displacement systems, and (2) value added systems. Cost displacement systems are intended to reduce unit costs by improving the efficiency of routine tasks or by eliminating them. The most common applications have been word processing and dictation to improve typing efficiency. Records management and administrative filing are two other applications. Cost displacement systems are usually the first step for most businesses and are aimed primarily at improving the productivity of secretarial and clerical personnel.

Value-added systems are those which increase the effectiveness of personnel and thereby enable them to perform additional functions. These systems include electronic mail, teleconferencing, management information, and decision support systems; and are directed primarily toward managers and professionals.

A second force contributing to the increased use of office technologies is their ready availability. The costs of electronic equipment have dropped considerably while labor costs continue to rise. It is, therefore, easier to justify the costs of new equipment which is promised to reduce manpower needs. Vendors are highly visible at trade shows and in professional journals and magazines, publicizing the message that office automation offers the solution to many problems. A third factor, which could be a cause or an effect of office technology applications, is increased control over work activities.

Potential Effects of Office Automation

New technologies can be used in offices in a variety of ways. Early advances in office technology such as electric typewriters and copying machines tended to mechanize certain office tasks. That is, they provided tools that workers could use to do their jobs better. However, some of these tools, beginning perhaps with the use of computers to replace card punch and accounting machines, actually replace human labor with electronic labor and, thereby, represent automation of office tasks. For example, word processors may perform the tasks of retyping and checking for spelling errors. Voice recognition systems may eventually replace the steno pool.

This definition of office automation has been expanded considerably, however, to include the use of virtually all types of technological changes. For example, Olson and Lucas (1982) indicate that "office automation" refers to "the use of integrated computer and communication systems to support administrative procedures..."; and Panko (1981) contends that "office automation ... embraces any tool to enhance the productivity or performance of office workers." Saffady (1981) believes that "Office automation involves the application of technology to the creation, storage, manipulation, retrieval, reproduction, and dissemination of information in the office environment." Clearly the use of some of the tools of office technology do not fit the traditional definition of automation. For example, teleconferencing does not directly replace human labor in the office. Some of these tools augment office activities in that they allow workers to perform new tasks or perform old tasks in better ways.

These distinctions are significant in that one of the major concerns of many groups, and in particular labor unions, is that workers will be displaced as "office automation" increases (Kirchner, 1982). Any projections concerning the impact of office automation on employment are problematic. The greatest concerns have been expressed in European countries where predictions are very pessimistic (Marsh, 1982; GAO, 1982). A U.S. government study concluded that most people agreed that some job loss would be experienced in the short run, but that long range projections were impossible to make (GAO, 1982). A report prepared for the International Labour Office indicated that microelectronics technology had not yet produced widespread displacement of workers, possibly because of a delayed rate of diffusion into the office (Wernecke, 1982).

It is apparent that certain occupations have already been hit by automation. Examples include typesetters and telephone operators and stenographers. The number of telephone operators declined by 75,000 (-19.4%) and the number of stenographers declined by 61,000 (49%) between 1972 and 1980. At the same time total employment was increasing by 19% (Leon, 1982). Future impact has been forecast for middle managers. This impact may occur in the form of displacement, deskilling or difficulty in finding work in a chosen field, often with attendant losses in earnings. While it is obvious that in certain cases jobs are eliminated, the number of white collar jobs has continued to increase at the clerical, professional, technical and managerial levels. BLS projections based upon continued growth of the economy suggest that more jobs will continue to be available through 1990 (Carey, 1981). Examination of these optimistic projections do, however, indicate wide variations in the relative rates of growth for different occupations. There is considerable debate about these projections, although more concern appears to be directed toward blue collar jobs.

The increase in the number of jobs available may not solve the problems of individual worker without some adverse psychological, social and economic effects. While there is little evidence to suggest that being displaced by computers is a serious concern of many office workers, labor unions are tending to seek job security agreements more frequently. For example, the recently negotiated agreement between Bell System companies and the Communications Workers of America (CWA) includes extensive contract language concerning training, retraining, income protection and early retirement. Thus, while craft employees and operators may be displaced from their current jobs, many will continue to work for the same employer, a trend which has been evident in the Bell System for years.

Another unique factor in low level clerical occupations which may attenuate the effects of automation on individuals is the high turnover rate. That is, high turnover rates may reduce the risk of job loss for individuals who wish to continue in the same occupation.

Office automation systems and other technologies can also affect workers by [illegible]ing the organizations they work in, the work environment and the [illegible] the job.

Organizational Effects. New technologies allow a choice between centralized and decentralized organizations. Since electronic networks allow communications between individuals at the same level and at different levels, certain positions, in particular middle management, may be redundant. In many cases, supervisors simply become enforcers with little control over work methods and decisions. Control over production may be shifted to programmers and higher management, making it more difficult for workers to communicate.

Face-to-face contact with other workers tends to be reduced at all occupational levels. A considerable amount of attention has recently been given to the potential for remote work (either in satellite work centers or the home) for clerical, professional, and managerial workers. While the advantages of reduced travel, flexible working hours and convenience for working parents and the handicapped are often mentioned, career opportunities and social contacts may also be diminished.

Physical Environment Effects. The major physical changes which occur in the work environment are related to the use of video display terminals. Studies have clearly demonstrated that a variety of ergonomic problems associated with the design of the VDT itself, lighting, and workstation design occur when these new tools of office technology are introduced.

Effects on Jobs. While it is argued that new office technologies can serve to increase job satisfaction by increasing task variety, skill requirements and feedback, this does not appear to be the case in all situations. Historically, technological innovations have been applied most often at the bottom of the hierarchy of jobs. At the clerical level, technologies may provide tools to perform work in an easier more efficient way, but the free time which results is filled with an increased volume of work. As a result, jobs become more simplified, repetitive and unsatisfying. Computer technology has seldom been used to upgrade clerical jobs. There is a deliberate endeavor to maximize efficiency and output, and there is greater pressure to work quickly and accurately, often at a pace set by a machine. Monitoring of work output becomes more common and is even considered essential by some experts in order to maximize efficient use of equipment (Kish, 1982; Meyer, 1980; Cyr, 1979).

The effects on professional, technical and managerial workers may be quite different since an alternate philosophy is generally applied. By providing the work force with tools which relieve the worker of routine tasks or assist in the performance of present tasks, it is reasoned that more time will be available for more creative work. Performance will improve and the worker will also be more satisfied.

The potential impact of reduced social contact due to electronic communication capabilities and "telecommuting" is difficult to assess.

The Impact of The Video Display Terminal

The video display terminal is the tool which acts as the interface between the worker and virtually all of the other office technologies described above. While optical character readers are already available and voice recognition and speech synthesizers are under development, the VDT will continue to be the instrument for communicating with office technologies throughout the present decade.

The VDT is the symbol of office automation to most workers and is almost synonymous with computers. Consequently, concerns and dissatisfaction with office technology are often directed toward VDTs. For example, workers voicing complaints about VDTs will often include response delays, "unfriendly systems" and excessive monitoring.

Questions about VDTs are a central issue for office workers (especially clerical workers) concerned about office safety and health. Some of the questions raised in relation to VDTs and associated technologies include:

- Do VDTs themselves present a hazard (radiation, visual problems, rashes, etc.)?
- Are VDTs properly designed?

- Do VDTs require special environmental considerations (e.g. lighting, workstations)?
- Do VDTs and associated technologies actually change the mental and physical demands of jobs?
- Do VDTs and associated technologies change the nature of work and organizations (e.g. control, social interaction, job security, career development, etc.)?

The significance of the concern about VDTs is affected by the number currently in use and the number that will eventually be in use. The potential impact of concerns about video display terminals must also be considered in terms of their uses in other settings. Microcomputers or personal computers are becoming more prevalent in occupations outside of the office. VDTs are already used in many of the service occupations, in industry, and even on farms. Finally, the impact of VDTs and technology must be considered in terms of their educational, recreational and consumer uses.

Microelectronics Applications

Clerical workers utilize video display terminals primarily for word processing, data entry and retrieval. Word processing may be carried out on a stand alone unit or on a microcomputer. Other activities are carried out on terminals linked to computers (or interactive VDTs). Estimates of the current numbers of interactive displays range from 7.1 (Dataquest, 1983) to 9.8 million (International Data Corporation, 1983). These estimates do not include stand alone units (i.e. word processors, personal computers, games, cash registers) or special use terminals (i.e. bank tellers, airline reservations, cashier systems). Dataquest (1983) projects that the number will reach 25 million by 1990. These figures do include programmer uses, management information systems, and data processing uses.

Personal computers (usually microprocessors) may or may not be included in the above estimates depending upon their use. The current number of personal computers used in business applications is estimated to be 2.6 million units and is expected to grow to 15-18 million by 1990 (Blundell, 1982; 1983). An additional 1 million units are used in the home (8.6 million by 1990) and .4 million units are used in schools (3 million by 1990), according to one source (Blundell, 1982).

The number of word processors already in use in 1979 was estimated to be 300,000 (Thoryn, 1979) and is certainly much higher today. One source estimates that word processors are currently used in 31% of all offices (NOPA, 1983). Table 1-7 provides one estimate of how microcomputers are used in large organizations. As can be seen, the largest increase in use is projected to occur in word processing applications.

Since these estimates of different uses overlap and, in other cases, do not include specific uses or multiple users, it is difficult to determine how many individuals are actually working at terminals or the number affected by automation. One management consultant estimated that 38 million white collar jobs may eventually be affected by automation (including 9 million managers, 14 million professionals, 5 million secretaries and supervisors and 10 million clerical workers), while a major manufacturer has suggested that 20 to 30 million will be affected by 1990 (Levitan and Johnson, 1982).

While most scholars and manufacturers are optimistic that normal economic growth will counteract job displacement, it is clear that work will be restructured, many skills will be devalued and workers (especially clericals and middle managers) will find it necessary to adjust. Employers will find it necessary to retrain large numbers of workers or seek qualified workers outside the organization, and labor organizations will expand their efforts to obtain security clauses in contracts.

TABLE 1-7*

Typical Uses of Microcomputers

	Percent of Total Applications	
	1982	1992
Dedicated to specific package	37	23
Word processing	7	44
Never used successfully	9	12
Departmental use	14	9
Engineering and scientific	21	9
Terminals	4	--
Payroll and accounting	7	3

*Adapted from International Resource Development, Inc. (Etelman, 1982)

CHAPTER 2

POTENTIAL OFFICE HAZARDS

Introduction

A variety of conditions related to office environments and work have been posed as potential health hazards by different interested parties. In this chapter, each of these problem areas and concerns will be addressed. These problems cover a wide range of environmental and work design issues, as well as a variety of different types of health effects which, for the most part, have received relatively little consideration from an occupational health and safety public policy viewpoint in this country. It is, therefore, necessary to re-examine the basic issue of what constitutes a health or safety hazard in order to provide a basic context within which each of these factors can be considered. In traditional health and safety terminology, a hazard is defined as a "potential source of harmful contact" (Bird, 1973) or a "condition with the potential of causing injury" (Hammer, 1976). These definitions imply that the condition is capable of causing harm and that contact is possible. The capability of a chemical to cause disease is referred to as its toxicity. A toxic chemical becomes a hazard when it exists in sufficient amounts to cause harm. The potential adverse effects of exposure to a hazard are also affected by the duration of exposure.

Given this definition of a hazard, it is then necessary to establish what constitutes harm or adverse health effects. There is little doubt that physical injuries and disease are adverse health effects. As will, however, become evident in the subsequent discussion of potential health hazards in offices, such physical impairments are often difficult to identify. At the same time there are a variety of other indicators of adverse health effects including pain and psychological distress. In the broadest sense, the definition of health can be expanded to include the absence of irritation and discomfort. Thus, Ashford (1976) described occupational safety and health as encompassing "not only the problems of preventing physical disease and injury, stress, psychological disorders and work alienation, but also the promotion of mental well-being and job satisfaction" (p. 45). Occupational health has been defined by the International Labour Organization and the World Health Organization (1963) as "... the promotion and maintenance of the highest degree of physical, mental, and social well-being of workers in all occupations, ..." (p. 4).

The definition of adverse health effects should then provide the basis upon which permissible exposure levels and control technologies can be established. It should be kept in mind, however, that the establishment of a permissible exposure level is also affected by a variety of other considerations including the possibility of synergistic effects, aggravation of pre-existing conditions, hypersusceptibility and potential long term effects, all of which may occur at lower levels. There is a tendency, therefore, to provide some margin of safety. On the other hand, public health decisions are also mediated by a number of non-health related considerations including socioeconomic and political factors. These will be discussed further in the sections on control strategies.

In order to accurately assess health and safety problems in the office environment, care must be taken to distinguish between factors which constitute hazards as described above, and those which are referred to as risk factors by epidemiologists. Hazard implies a causal relationship while risk factor implies only a predictive relationship. This distinction is important for two reasons. First, much of the research related to office health and safety is based upon surveys in which correlations are established between adverse health outcomes and various aspects of the work environment. Secondly, in order to adopt the most appropriate control strategy, causes rather than risk factors should be identified. The most pertinent example in office work concerns the use of video display terminals. As will be shown, a number of studies have reported a higher incidence of visual complaints among VDT operators as compared to traditional office workers. If the actual cause of the vision complaints can be related to factors such as image quality or screen flicker, then the VDT constitutes a hazard. If the vision complaints arise out of the fact that the VDT task studied involves more intensive and sustained visual work than the comparison task, the VDT represents a risk factor. In the first case, control strategies would be directed toward the design of the equipment and in the second case toward the design of the task.

Summary

If a given factor is, by its nature, capable of causing adverse health effects at levels which may be shown to exist in office environments, it can be judged to constitute a hazard. The two major questions to be examined with respect to each of the factors discussed are: (1) to what extent does the factor exist within the environment and (2) what type of adverse health effects can be associated with the existence of the condition.

In terms of public policy decisions, judgments must ultimately be made by those responsible for the protection of worker health and well-being, based upon the extent to which the condition occurs and the desired level of protection to be afforded to office workers.

Stress

Stress is currently one of the most pervasive health problems in the United States. The American Academy of Family Physicians has suggested that two-thirds of office visits to family doctors are prompted by stress-related symptoms (Time, 1983). Michael Smith, Chief of NIOSH's Motivation and Stress Research Section, recently wrote:

> "Emotional disturbances of an acute, neurotic nature (distress syndrome) are at epidemic proportions in the U.S., according to the latest statistics from the National Institute of Mental Health ... Such disorders accounted for more than 15 percent of the total workers compensation costs in California in 1980 and have steadily grown each year. Today 19 states recognize such emotional disorders as being, potentially, work related and award compensation" (Smith, 1982, page 18).

According to Paul Rosch, Director of the American Institute of Stress, "Stress management has become a multimillion-dollar-a-year business" (Time, 1983). Mental health experts estimated that there were over 130 methods of therapy or techniques for coping with stress in 1979 (Wall Street Journal, 1979), and there are, by some estimates, more than 300 stress-management enterprises offering their services to hospitals, clinics and corporations around the country (Time, 1983). It is clear that problems at work are currently one of the major contributing factors in stress (Cooper and Payne, 1978, 1980).

All types of office workers have been considered as prime targets for potential stress risks. While early studies concentrated on "executive stress" more recently the focus has turned to middle management and clerical workers. A NIOSH study (Colligan et al., 1977) reported that secretaries had the second highest incidence of stress-related diseases of 130 occupations evaluated. Office managers and manager-administrators were also among the 12 "high stress" occupations. Results from the Framingham Heart study indicated that women holding clerical jobs had coronary heart disease rates twice as high as housewives (Haynes and Feinleib, 1980).

The relationship between stress and certain diseases are well-established (e.g. ulcers, coronary heart disease, diabetes and arthritis). In addition, there is a growing body of evidence suggesting that stress affects the body's general resistance to disease, thereby increasing susceptibility to everything from the common cold to cancer. However, in the workplace other measures of stress are necessary, including attitudinal variables such as job dissatisfaction; emotional states such as tension, anxiety, anger, and frustration; somatic complaints such as muscular tension, headaches, and gastrointestinal problems; or behavioral variables such as drinking, smoking, medication use, drug use, and absenteeism. While the relationship between stress and these outcomes are not always clear and unequivocal, it is readily apparent that stress is a major contributing factor. It goes without saying that the costs in terms of both degraded health and well-being and economic burdens are potentially staggering. Based on national samples, stress-related symptoms have been estimated to cost industry $50-75 billion a year in absenteeism, company medical expenses and lost productivity (Time, 1983).

Some of the most frequently described sources of stress for clerical workers include:

- monitoring
- machine pacing
- lack of promotional opportunities
- low pay
- monotonous and repetitive work
- environmental conditions (e.g. temperature, air quality, and ergonomic problems)
- lack of feedback
- underutilization of skills

- production quotas
- lack of participation and control
- overtime
- unsupportive bosses or supervisory problems
- sexual harassment
- conflicts between home and work demands
- piecework

A list such as the one above can be developed simply by asking a group of workers what bothers them. The fact that these conditions are sources of complaints does not, however, indicate the extent of risk associated with clerical jobs. Two questions must be answered. First of all, the frequency and degree to which these conditions exist in the work environment must be determined (exposure); and secondly, the effects which they may have on individuals must be determined. For example, rigid production quotas might be imposed upon 30% of all typists, but only 5% of those exposed may be bothered by them. Nearly 100% of all clerical workers are exposed to low paying jobs but the number bothered by this condition (at least to the point of feeling stress) is much lower.

Thus, a low frequency of reported concerns about lack of promotional opportunities may be accounted for by the fact that promotional opportunities are available, or that many individuals do not have aspirations to be promoted. The prevalence of some of the potential sources of stress listed above have been estimated from surveys of certain occupations. Unfortunately, there have been few national samples which provide clear indications of the pervasiveness of stressful conditions or stress symptoms among office workers.

Effects of Automation

The automation of offices has led to increasing concerns about new or more extreme sources of stress including increased boredom, monotony, job insecurity, job future uncertainties, lack of job control, increased monitoring, job fragmentation, alienation, and job dissatisfaction. Broad statements about the effects of automation are difficult to make. It has been suggested that automation offers the opportunity to eliminate tedious, difficult and boring work. It would appear that in some cases this is indeed possible. However, management has choices concerning how automation will be used. At one extreme, the technology can be introduced under the control of workers to make their jobs easier. At the other extreme, workers are told exactly how to do the work and are closely monitored (scientific management) (e.g. Cyr, 1979; Meyer, 1980). It appears that the former option is being primarily reserved for professional and managerial uses of new technologies.

The most frequent applications of mechanization and automation in offices have, to date, been directed toward clerical jobs (i.e. bookkeepers, secretaries, typists, bank tellers, and insurance workers). It is quite clear that in such applications the principles of scientific management have had a major influence. Scientific management advocates the deskilling and fragmentation of jobs. Tasks should be simple, short-cycled and repetitive, thereby lending themselves to more control by allowing management to specify the "correct method" and closely measure performance (Saffady, 1981). When these principles are followed, clerical jobs which are, in many cases, already simple and repetitive become even more so.

In the words of Frederick Taylor, the "father of scientific management," "under scientific management the 'initiative' of the workmen (that is, their hard work, their good will and their ingenuity) is obtained by absolute uniformity and to a greater extent than is possible under the old system; and in addition to this improvement on the part of men, may the managers assume new burdens, new duties and responsibilities never dreamed of in the past." Taylor also, however, foresaw one of the major obstacles to the application of scientific management "Without the element of stupidity, the method would never work. A pig iron handler shall be so stupid and phlegmatic that he more resembles the ox than any other type ... The man who is mentally alert is entirely unsuited to what would, for him, be the grinding monotony of work of this character" (Taylor, 1911 pp. 36-52). In 1981, only 13% of all male clerical workers and 7% of all female clerical workers had less than a high school education. Twenty-eight percent of the males and 23% of the females had some college and 18% and 9% respectively had college degrees (Bureau of the Census, 1983). In spite of this warning and incongruity, many industrial engineers and management consultants extol the need for such methods if productivity gains and returns on capitol investments are to be realized. Seldom has automation been used to deliberately upgrade clerical jobs.

It is apparent then, that microelectronics technology can be used to make work easier, and many workers (including clericals) report this to be true. However, if the fact that a worker can perform the same amount of work with less energy results in reorganization of work, fragmentation of jobs and increased repetitiveness, decreased job satisfaction and stress can also be expected to increase. Two other aspects of scientific management are also particularly easy to implement in mechanized or automated jobs - monitoring and piecework. The use of a computer makes both very simple since it can accurately record activity on a continuous basis. Many word processors come with features which allow a printout of total task time, number of lines typed and number of keystrokes. Adverse effects of both monitoring and piecework on clerical workers health and well-being have been documented in a number of studies (Cakir et al., 1980; Levi, 1967, 1972; Guttormson and Smith, 1971).

Another potentially stressful aspect of the introduction of new office technologies (which is less easily controlled by management) is the element of machine pacing involved in such jobs. Murphy and Hurrell (1979) have reviewed a variety of studies and found expressions of high job dissatisfaction, tension, underutilization of abilities, frequent health complaints, nervous disorders and a variety of psychosomatic complaints among machine paced workers. While computer control of work pace is of a different nature and degree than that found in many of the jobs from which these results were obtained, it has frequently been observed that machine control of office work pace (especially delays or breakdowns) are a source of worker complaints.

The results of studies comparing VDT and non-VDT work tend to confirm the theory that broad generalizations about the effects of new office technologies should not be made. For example, Sauter et al. (1982) reported that "VDT work did not contribute to psychological distress or job dissatisfaction to any greater extent than non-VDT clerical work" among the group of workers studied. Other studies have reported similar findings (Starr et al., 1982; Sauter et al., 1981; Dainoff et al., 1981; Coe et al., 1980). Thus, the conclusion that VDTs and related technologies do not have to increase psychological stress and job dissatisfaction seems warranted. In fact, a number of studies report some positive aspects and feelings about VDTs (Hunting et al., 1981; Starr et al., 1982; Dainoff et al., 1981; Gunnarsson and Ostberg, 1977; Cakir et al., 1978; Gunnarsson and Soderberg, 1980; Johansson and Aronsson, 1980) especially relating to making certain tasks easier. At the same time, a number of studies have clearly indicated that VDT tasks with certain characteristics are more stressful than both non-VDT and other types of VDT work (Smith et al., 1981; Gunnarsson and Ostberg, 1977; Cakir et al., 1978; Elias et al., 1980; Canadian Labour Congress, 1982). The most frequently mentioned variables were monotony and boredom, monitoring, piecework, loss of control over work pace, technical problems or interruptions, and production quotas.

A NIOSH report (Smith, 1982) concluded, "It appears that job design factors, primarily highly paced work, lack of control and pressures such as deadlines, are more prevalent in some types of VDT work than in others. These factors have been shown to be related to many of the health complaints that are reported by VDT operators and could be linked to serious health disorders" (p. 24).

It is important to reiterate at this point that a finding of no differences between VDT work and non-VDT work may be completely unrelated to the question of how much stress is involved in clerical work. For example, Sauter et al. (1982) after indicating that no differences were found between VDT and non-VDT clerical workers went on to say " ... but stress does predict health complaints, job dissatisfaction and emotional states for both." Examination of some of the other studies indicating no differences reveals similar results. For example, the data reported in the Starr et al. (1982) study indicate that of five dimensions of job satisfaction rated on a scale of zero (dissatisfaction) to 54 (satisfaction), the mean scores for the non-VDT and VDT telephone operators combined were: work in present position (20); present pay (31); chances for promotion (23); supervision (38); and people in present job (37). Since the midpoint of the scale is 27, it must be concluded that either most of those studied are moderately dissatisfied with certain dimension (e.g. work and chances for promotion) or that a significant number are highly dissatisfied. Thus, the conclusion that no differences between automated and non-automated work exist should not be a reason for lack of concern. Analyses of the results of other studies reveal similar findings.

The potential implications for managers and professionals are similar but data is scarce. The few studies involving professional VDT users have not shown any substantial effects. Professionals generally report fewer problems than clericals, however. The lack of information is particularly significant since industry predictions of the future growth of office automation are usually based upon a high rate of future use by professionals and managers. While some of the factors impacting clerical workers (e.g. monotonous and repetitive work, job fragmentation, etc.) are not expected to occur to such a great extent, other factors could. Job displacement (especially for middle managers), machine control, information overload, technical problems, performance monitoring, resistance to change, and ergonomic problems are examples.

Controlling Workplace Stress

There are basically two approaches that can be used to alleviate stress in the workplace. The first involves changing the worker and is embodied in stress coping or stress management techniques. The second approach involves changing the design of the job, organization or environment in order to remove the sources of stress.

Stress Management. By far the most common approach has been the former -- changing the worker. As indicated earlier, there appears to be an endless variety of proposed techniques and methods for coping with stress. Numerous organizations now offer stress management services to industry. While company sponsored stress management programs are most commonly offered for managers, they are in many cases available to professional, technical and clerical workers as well. The principle advantages to organization in using these approaches are: there is no requirement to make any changes at the workplace; management does not have to accept the blame for stress; and they are readily available. From a theoretical standpoint, the principle advantage is that they may be applied (if effective) to any type of stressor, on or off the job. The biggest problem with such approaches is that there is very little evidence that they are effective (Wall Street Journal, 1979). Table 2-1 summarizes the principle advantages and disadvantages of stress management techniques.

Controlling the Source of Stress. The second approach involves reducing or eliminating the source of stress. There are two levels at which control of stressors can occur. First, environmental sources of stress can be controlled (i.e. heat; air quality; uncomfortable chairs, workstations and working positions; noise; and lighting). The environment is adapted to better fit the worker. The second level of control involves reducing or eliminating stressors which arise out of organizational structure, job design or work tasks (e.g. monotonous jobs, lack of control, monitoring, machine pacing, piece rates, opportunity for promotion, etc.). These approaches, when carried out systematically, are variously referred to as "humanization of work," "worker participation," "quality of working life (QWL)," or "job enrichment." An attempt is made to reduce the stress problems by changing work so that it better fits the needs and capacities of workers. Jobs are enlarged or enriched, greater control is given to workers, social interaction is increased, workers are given greater responsibility, boring tasks are made easier through automation, and promotional opportunities are increased. Each of these steps may remove sources of stress from the job.

TABLE 2-1

Advantages and Disadvantages of Alternate Stress Control Methods

STRESS MANAGEMENT

Advantages	Disadvantages
1. Easily available.	1. Needs constant and continuing reinforcement.
2. Assume no blame.	2. Unproven by scientific data.
3. Deals with stress on and off the job.	3. Source of stress remains.
4. No restriction on job design.	4. If worker leaves, investment leaves.
5. Deals with variety of stressors.	5. Costs associated with exhaustion of coping resources.
6. No restriction on product design.	6. Expensive.
	7. Depend upon participation.
	8. May be adverse side effects.

ERGONOMICS - JOB DESIGN

Advantages	Disadvantages
1. Hazard is removed.	1. Requires coordinating at top level management.
2. Changes are permanent, affects all new workers as well.	2. Potentially high initial costs.
3. Potential productivity increases.	3. Lack of empirical data, especially productivity pluses.
4. Increased flexibility.	4. Only deals with one source at a time.
5. Reduced turnover.	5. Does not deal with individuals who have hypersusceptibility.
	6. Does not deal with personal sources of stress.

The principle advantage of job and environmental redesign is removal of the source of stress. Furthermore, the change can be permanent, affecting all workers who subsequently hold positions. In addition, claims of increased productivity are often made. Environmental changes may be costly, but have few other disadvantages. Organizational or job design changes represent a release of control by management, and are therefore, approached with much greater caution. Other advantages and disadvantages have been listed in Table 2-1.

Obstacles to Implementation of Control Strategies

There are few obstacles to implementation of strategies directed at changing the worker beyond the potentially high cost. Since a stress management program must be continuous and ongoing at all time in order to be effective, these costs can be substantial. Furthermore, the effectiveness of the program is predicated upon participation. Many such programs fail for this very reason. The most important question is, however, whether they are actually effective even with participation. There is very little scientific evidence indicating that they are.

The advantages of good working environments are fairly well documented (Harris, 1980; BOSTI, 1983). The obstacle is once again cost. Managers are seldom able to justify large investments in the work environment simply to increase job satisfaction or decrease job stress. Another incentive is required and it is usually productivity. If the investment in capitol can be justified in terms of a pay back via increased productivity, the chances of making improvements in the workplace are tremendously increased. The BOSTI study estimated that the effect of good office design on job performance of managers and supervisors was $1600 per year per person; and almost $1700 for professional and technical workers (Westinghouse, 1983). The effect of good office design on job satisfaction amounted to over $400 per year for clerical workers. Other case studies are reviewed by Channer (1983).

While the virtues of humanization of work and QWL programs are frequently described in the press and discussed by academics, they are in fact seldom used. A New York Stock Exchange Study (1982) estimated that only 14% (7000) of the 49,000 corporations employing more than 100 people were involved in some type of human resource program (employee involvement) activity. Among corporations employing 500 or more employees: 46% of these programs included job design/redesign; 45% included surveys of employee attitudes; and 25% included labor management committees. Of the corporations employing more than 500 workers: 67% reported improvements in employee attitudes and morale; 55% increased productivity; 45% improved safety records; and 39% reduced absenteeism and turnover. In spite of reports such as the NYSE study and other reports describing the disadvantages of Tayloristic principles (e.g. U.S. HEW, 1973) and the advantages of worker participation and work humanization, it is obvious that the majority of employers remain unconvinced. Activity and interest will undoubtedly persist at some level, however. At least 22 states have funded QWL studies to evaluate the levels of activities within their states (Davenport, 1983).

The obstacles described above are indicative of the existence of a more basic problem. That is, there are no adequate measures of the costs of job stress. While it has frequently been suggested that sick time, absenteeism, turnover, and reduced productivity reflect levels of job dissatisfaction and stress, these relationships have never been adequately quantified. While workers' compensation costs for stress related illness are on the rise, they do not yet constitute a significant financial burden. In brief, economic factors are not perceived as a significant incentive for reducing job stress.

Developing a Public Policy

The major difficulty involved in the development of strategies for reducing stress in the workplace relates to the difficulty of assessing risk. Control strategies are typically evaluated in terms of their ability to reduce risks to acceptable levels. For example, noise standards are established to assure that only a certain relatively small percentage of those exposed will experience a certain level of hearing loss. Likewise, an exposure level for a chemical can be established to assure that the risk of cancer will not be increased significantly. It is very clear that the establishment of standards for exposure to psychological stressors based upon the risk of developing ulcers, CHD or psychosis will not be satisfactory. Workers want to be free of the immediate tension, anxiety and frustration that they experience.

Some other approach is therefore necessary. The philosophy behind ACGIH TLVs (1983) offers a good model "The basis on which these values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, or other forms of stress may form the basis for others."

Ergonomic Problems

Included in the first reports from Europe concerning potential adverse health effects associated with VDTs were accounts of frequent complaints about musculoskeletal and visual problems. These accounts also pointed out potential problems inherent in the design of commonly used displays, keyboards, work tables, chairs and lighting. Other studies soon demonstrated that there were often clear differences in these health problems which depended upon the types of task users performed. These reported health problems were therefore assumed to be caused by the poor fit between the worker and various aspects of the work environment. The discipline which has traditionally dealt with such concerns is called ergonomics. Ergonomics is the study of the relationships between the worker and the work environment. As generally understood, the basic philosophy of ergonomics is "designing work to better fit workers". Equipment and jobs which are not so designed can lead to psychological and physical stress that may affect health and well-being as well as performance.

While ergonomics as a field of study has a long history of research related to both industrial and office work, VDT-related health concerns have revived interest and popularized the subject, especially in the United States. Early U.S. studies of VDT-related complaints concluded that a variety of ergonomic problems existed. Three of these "ergonomic problems" will be considered in this section: musculoskeletal problems, visual problems, and fatigue. Poor design of equipment, jobs, or work environments may produce such problems.

In assessing the extent of such problems, two questions must be addressed. First of all, the frequency and seriousness of these problems among office workers must be considered. Secondly, the potential effects of office automation and specifically the use of VDTs must be considered.

Musculoskeletal Problems

Numerous reports of musculoskeletal problems among office workers are available. Problems range from complaints of discomfort to pain and medical disability. The most frequent sources of complaints are the back, neck and shoulders. Less frequent complaints concern the arms, wrists, hands and occasionally the legs.

Reported results from various studies are very difficult to compare since different measures of the seriousness and frequency of problems have been used. In addition, numerous studies have shown that the type of task being performed has an important bearing on the type of problems encountered. Table 2-2 indicates the percentage of workers typically reporting various problems on a "frequent" or "daily" basis, and is based upon the results of five studies.

The results of studies comparing VDT and non-VDT office workers have been inconsistent. It is generally agreed, however, that the type of task has a major influence on the results, which is often difficult to partial out. Two studies which attempted to do this by matching tasks (Starr, et al., 1982) and through multivariate analysis (Sauter, et al., 1982) came to the conclusion that the VDT itself did not contribute to muscular stress. While such studies seem to vindicate VDTs, it is readily apparent that the VDT plays a major role in determining the nature of the job and the adequacy of the workstation. In other words, the problem concerns the way the terminal is used. This has a significant bearing on the selection of appropriate control methods. A variety of studies relating to musculoskeletal problems have been reviewed by Arndt (1983).

Theories concerning the causes of problems are based upon biomechanical, physiological and anthropometric considerations. Poor working positions place greater loads on muscles, tendons and joints which increase the rate of fatigue. Constrained or static working positions lead to even more rapid fatigue. Chronic exposure to such stress may eventually result in physical disorders. Repetitive motions, especially of the hands and fingers may also lead to cumulative trauma disorders. Thus, the working posture as determined by the design of the workstation and the individual worker's body size; the

TABLE 2-2

Frequency of Reported Musculoskeletal Problems From Various Studies

	Percent Reporting Frequent or Daily Problems[1]		
	Neck-Shoulder	Back	Arm-Hand
Hunting et al., 1981 (n=295)			
VDT operators	6-12	6-10	6-12
Typists	6-12	6-10	6-10
Traditional office	2-5	2-5	2-5
Canadian Labour Congress, 1982 (n=2200)			
VDT	10-12	10-15	2-3
Non-VDT	7-8	9-14	4
Sauter et al., 1983 (n=333)			
VDT	24-34	27-35	3-4
Non-VDT	19-28	22-29	4-6
Hunting et al., 1980 (n=414)			
Data entry VDT	11-15	N.A.	6-15
Accounting machine	3-4	N.A.	8
Conversational VDT	4-5	N.A.	7-11
Typist	5	N.A.	4-5
Traditional office worker	1	N.A.	1
Arndt, 1980 (n=987)			
Telephone operators[2]	8-17	15	12
Service assistant[2]	9-14	14	6
Accounting clerks[2]	7-10	10	5

[1] Results include percent reporting almost daily, frequent, often constant. Ranges represent multiple questions.

[2] Approximately 33% use VDT

N.A. = Not available

amount of time the position must be endured without adequate rest; and the frequency of certain motions, all may contribute to musculoskeletal problems in the form of fatigue and muscular pain; or inflammation of tendons, joints or muscles.

Based upon these considerations, a number of potential risk factors have been identified (Figure 2-1). The factors responsible for the occurrence of these risks have been identified as equipment design problems (including VDTs, workstations and chairs); and job design problems (including constrained working positions, repetitive work and inadequate rest breaks). As a result, recommendations, guidelines and in some cases standards have been proposed to alleviate some of these sources. Table 2-3 describes the type of design features which have typically been addressed.

Control Methods For Reducing the Incidence of Musculoskeletal Problems.

Ergonomic design. The most frequently recommended control measure is ergonomic design. The market has attempted to respond to this demand by providing "ergonomic terminals," "ergonomic workstations" and "ergonomic chairs". Although manufacturers have been slow to respond, nearly all companies now offer a VDT workstation and many offer adjustable workstations. Virtually all chair manufacturers are offering new "ergonomic" chairs. While only 6% of all office chairs are of this type, it is one of the fastest growing segments of the furniture industry and it has been estimated that by 1988 the number will reach 20% (NOPA, 1983). The cost of fixed budget grade VDT tables are in the range of $100-$300. The cost of an adjustable work table may be as low as $200 for those with a few features to more than $1300 for fully adjustable powered workstations. "Operator" or "task" chairs list for prices between $300-$700 (discounts are usually available). This is

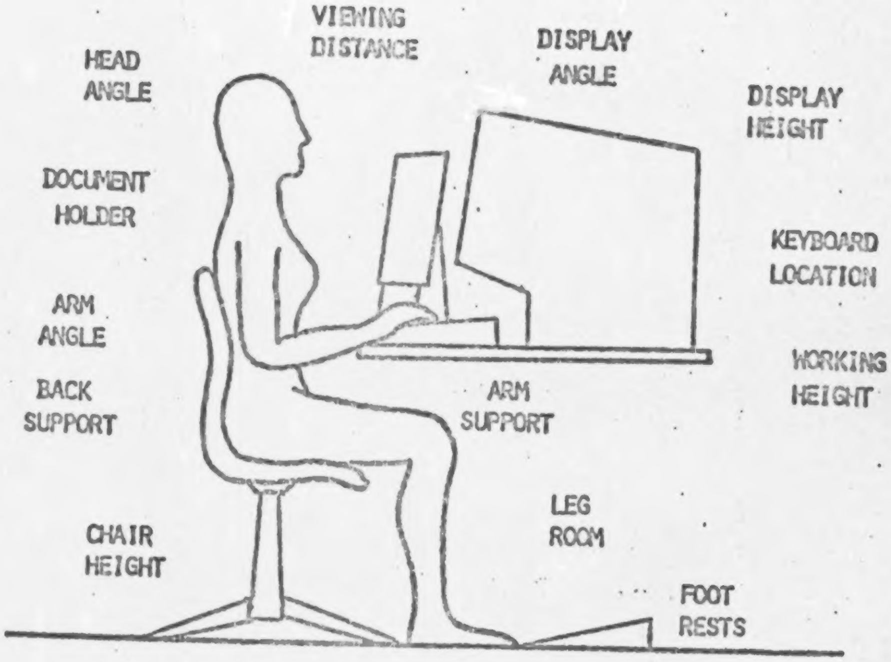

HEAD ANGLE
VIEWING DISTANCE
DISPLAY ANGLE
DISPLAY HEIGHT
DOCUMENT HOLDER
KEYBOARD LOCATION
ARM ANGLE
WORKING HEIGHT
BACK SUPPORT
ARM SUPPORT
LEG ROOM
CHAIR HEIGHT
FOOT RESTS

FIGURE 2-1. Potential ergonomic risk factors associated with office workstation design.

TABLE 2-3

Ergonomic Design Features Addressed by Standards and Guidelines

	Features
VDTs	Keyboard thickness Detachable keyboard Keyboard angle Keyboard layout Keyboard design Key tension
Workstation	Display height Keyboard height Display and keyboard distance Display and keyboard angles Adjustability
Chair	Backrest design, position and adjustment Height adjustment Seat pan design Ease of adjustment
Job Design	Total time on VDT Frequency of rest breaks Compensatory job activities Degree of variation in tasks

approximately 2-5 times the cost of the traditional budget grade secretarial or typist chair. Pneumatic adjustments add to the cost and make adjustments easier but are considered unreliable by many purchasers (NOPA, 1983). Ergonomic design features are now incorporated in many video display terminals and do not significantly affect the original purchase price of terminals.

A number of problems related to the implementation and effectiveness of this approach are evident:

1. the relationships between specific design features and musculoskeletal problems have not been empirically verified in all cases,
2. worker preferences may not coincide with ergonomic principles,
3. with the variety of features available, purchasers have difficulty determining which are necessary to solve their problems,
4. advertising hype about the ergonomic design of equipment is often inaccurate and useless, further complicating the picture,
5. little attention is given to non-VDT workers.

Job redesign. One of the most consistent results of research on musculoskeletal problems has been the recognition of the importance of the type of task being performed. Jobs which are highly repetitive and those involving constrained postures are associated with higher incidence rates of almost all musculoskeletal problems. Proposed solutions include enlarging jobs to increase the variety of activities performed and rotating workers to different jobs.

Two major obstacles are often present. First, in many industries there is not a sufficient variety of jobs or tasks available to allow the degree of freedom necessary in redesigning jobs. The second obstacle is the immediate additional training cost and the potential for increased labor costs inevitably associated with jobs requiring more skills.

There is also a tendency to believe that simplification of jobs increase productivity. Most of the advantages of job enlargement beyond the potential reduction of musculoskeletal problems are intangible and difficult to assess. These include such things as increased job satisfaction, reduced turnover, improved motivation, and greater perceived control.

Exercise. To the extent that constrained working postures contribute to musculoskeletal stress, regular exercise offers a potential source of relief. Other advantages are difficult to assess. Some reports are available that attest to the economic benefits of exercise components of health promotion programs in reduced illness and absenteeism (Fielding, 1979). In order to be effective, exercise would have to be interspersed throughout the day and would represent lost productive time.

Rest breaks. The effectiveness of frequent rest breaks has often been demonstrated in both industrial and office situations, according to Cakir, et al. (1980). In order to be effective, a rest break must be taken before significant fatigue occurs. Various recommendations concerning the frequency of rest breaks for VDT operators have been proposed (Table 2-4) by a number of parties. The scientific data available on the subject of rest breaks for office workers, comes from Japanese field studies. Using a variety of measures (work rates, errors, autonomic reactions, complaints, cervico-brachial disorders, and electromyography), these studies have led to a commonly recommended limit for continuous work of about 45-60 minutes, followed by breaks of 10-20 minutes. In Japan, many work places involving keyboard operations now comply with the 60 minute work and 10-15 minute rest cycles recommended by The Ministry of Labor notification (Kogi, 1982). It is generally agreed that intensive, repetitive work involving close visual work requires more frequent breaks.

TABLE 2-4

Break Schedules Recommended by Various Groups

Type of work	Minutes/hours	Source
Moderate visual demand	15/2	NIOSH recommendations,
High visual demand	10/1	Massachusetts Bill
Close work	15/1*	Australian Council of Trade Unions
Terminal work	15/2	Maine and Illinois bills
VDT work	15/1*	Newspaper Guild Model State Act
	15/2	
Terminal work	15/2*	Oregon Bill
Terminal work	20/2*	New York Bill
Moderate demands	15/2	National Association of Working Women
High demands	15/1	

*Rest or alternative work

Additional rest breaks represent lost productive time. Most employers find it difficult to overlook this fact and are unwilling to trade this loss for an unknown return in terms of reduced incidence of health problems or higher motivation and subsequent increases in overall effort and productivity. In some cases, this objection can be overcome by providing alternative work rather than additional rest breaks.

Medical evaluations. Periodic medical surveillance in the form of examinations or surveys of workers offer the possibility of detecting problems before they become disabling. Such information can also provide insight into the causes of such problems and may prove useful in the selection of preventive measures.

Summary. It is apparent that office workers experience a significant number of musculoskeletal problems. While most of these problems represent discomfort or pain, the potential for more serious problems certainly exists, especially when exposure is long term. The consequences cannot easily be measured in workers' compensation costs or lost time. For example, in the state of Wisconsin there were only five cumulative trauma injuries reported among secretaries and typists in 1982 (Wisconsin, 1983). It may also be difficult to establish the effect upon productivity. Thus, perceived economic consideration probably do not constitute a major incentive to eliminate such problems. It has been commonly observed that investments in any type of control will generally hinge upon some other motive. The most frequently asked questions in this regard concern potential increases in productivity. While there is evidence that increased rest breaks may result in increased productivity, it is not familiar to, or sufficiently convincing to most employers. While other ergonomic solutions intuitively should improve performance, there is, unfortunately, very little evidence related to office settings to support this intuition. Two studies involving VDT tasks have reported productivity improvements in laboratory settings (Dainoff, et al., 1982; Springer, 1982).

Visual Problems

Vision problems (including eyestrain and burning/itching eyes) are frequently reported by all types of office workers and complaints occur more often in many VDT tasks. Other less frequent complaints include blurred vision, double vision, color fringes, and deterioration of acuity. Most of these complaints have surfaced as VDT-related problems, although they can usually be found in any type of work involving intensive visual demands. Table 2-5 presents a summary of typically reported rates of "frequently experienced" problems for VDT and non-VDT workers. Again, the issue of whether these experiences are somehow associated with the VDT itself has frequently been raised. A recent review of existing literature by a National Research Council panel (1983) led to the following conclusion:

> "We find no scientifically valid evidence that the use of VDTs per se causes harm, in the sense of anatomical or physiological damage, to the visual system. The symptoms of ocular discomfort and difficulty with vision reported by some workers who use VDTs appear to be similar to symptoms reported by people performing other near-visual tasks. Temporary changes in measures of visual function reported to occur following VDT work appear to be similar to those observed after performance of near-visual tasks in non-VDT jobs" (p 2-3).

It is a well-established fact that intensive use of the eyes leads to eyestrain and other subjective symptoms. There is also a long standing controversy concerning the relationship between close visual work and nearsightedness (Bear and Richler, 1982; Taylor, 1982). While a number of studies have noted transient functional visual changes (minutes to hours in duration) after performing VDT and other close work, there does not appear to be adequate evidence at this time to support the conclusion that permanent changes

TABLE 2-5

Frequency of Reported Visual Problems From Various Studies

	Percent Reporting Frequent Problems[1]		
	Eyestrain	Burning, itching, irritation	Blurring, double vision
Sauter et al., 1983 (n=333)			
VDT	24	19-27	5
Non-VDT	20	21-23	5
Laubli et al., 1980 (n=404)			
Data entry VDT	20	N.A.	N.A.
Conversational VDT	28	N.A.	N.A.
Typists	18	N.A.	N.A.
Traditional office	5	N.A.	N.A.
Canadian Labour Congress, 1982 (n=2269)			
VDT	N.A.	9-17	13-16
Non-VDT	N.A.	7-8	8-9
Sauter et al., 1982 (n=123)			
VDT newspaper editors	40	43-46	N.A.
Non-VDT newspaper editors	17	17-22	N.A.
Arndt, 1980 (n=987)			
Telephone operators[2]	8	N.A.	1-5
Service assistants[2]	9	N.A.	1-4
Accounting clerks[2]	6	N.A.	1-3

---

[1] Frequency of problems reported daily, constantly, often, very often, frequently.

[2] Approximately 33% used VDTs.
N.A. = Not available.

occur (NRC, 1983). Many of the problems involved in evaluating vision complaints center around the difficulty of establishing the relationship between subjective complaints (e.g. eyestrain) and objective correlates.

A few studies (Starr, et al., 1982; Gould and Grischkowski, 1983) have demonstrated that under certain conditions, no differences can be observed between VDT and non-VDT work. This does not deny the fact that large numbers of office workers experience visual problems (regardless of the equipment used) nor that those working with VDTs tend to experience more frequent problems, as indicated in Table 2-5. Other studies have been reviewed by NRC (1983) and Helander, et al. (1982).

Visual Demands. The most consistent finding is that the intensity and duration of the visual demands of the job (regardless of whether a VDT is used or not) are correlated with the frequency of eye complaints. The difficulties encountered in attempting to quantify both visual demands and visual problems have so far prevented the formulation of clear and definitive guidelines for preventing or abating problems in actual work situations. Moreover, there are no clear studies which have established the efficacy of reducing visual demands through job redesign or more frequent breaks.

A number of theories have been advanced concerning potential risk factors. As mentioned above, close visual work has been one of these. Other established risk factors are the clarity and perceptibility of the image (including font, contrast, color, etc.) and illumination (including contrast, glare, reflection). Research has not yet established which factors are most important in office work. Correlations between symptoms and expected risk factors are typically small. This might suggest that a number of factors interact or that different factors produce the same results in different situations.

It has also been suggested that pre-existing visual deficiencies may surface more readily in visually demanding office tasks (Dickerson, 1976; Ostberg, 1977). While this has been established in some cases, it cannot totally explain the high frequency of problems witnessed (Smith, et al., 1982).

Eye Examinations. While there is currently no evidence that viewing VDTs leads to pathoanatomical changes, it is generally agreed that preplacement visual examinations for office workers employed in visually demanding tasks are an effective and worthwhile preventive measure. The evaluation of any types of eye problems being experienced by workers should also include an appropriate examination. The American Optometric Association (AOA, 1980) has reviewed eye examination requirements and recently recommended that VDT operators take steps to protect their own vision by seeking annual eye examinations (Chicago Tribune, 1983). The National Society for the Prevention of Blindness has also pointed out the essential requirements of preplacement visual testing including an emphasis on the job relatedness of the evaluation (Hirshfelder, 1980). These recommendations have been affirmed by NIOSH (Murray, et al., 1981). Other recommendations for eye examinations have been included in Cakir, et al. (1980, Appendix II); Desnoyers and LeBorgne (1982) and Whycer (1978). Most of the VDT safety and health bills introduced at the state level have included prescriptions for eye examinations.

The suggestion that eye fatigue among VDT operators can be lessened by the use of tints or color filters (American Academy of Ophthalmologists, 1982) is, however, highly questionable. As pointed out by Snyder (1982), tinted glasses may reduce VDT contrast, leading to greater difficulty in viewing while not effectively reducing potential sources of strain such as glare and screen reflections. Reading glasses, refracted for the actual viewing distance involved in a task, may be very helpful to individuals who wear glasses (especially bifocals).

Image Quality. The well-established relationships between the clarity and quality of the visual image and potential vision problems have led to a variety of suggestions for improvements in office work. Most of these have concentrated on VDT characteristics. These guidelines have included descriptions of optimal character size, font type, and minimum contrast. Other specifications which are aimed at less clearly established risk factors have concerned image color and negative contrast (dark characters on a light background). Since the image on the cathode ray tube must be repeatedly renewed, the characters may be subject to perceptible flicker or luminance variations and jitter or movement on the screen. While it is technologically feasible to alleviate or reduce all of these problems, different manufacturers have addressed them with varying degrees of vigor and success. In addition, many older models are still in use and are likely to remain in offices for some time. According to the National Research Council report (1983) "In many instances, however, VDTs have been designed without attention to existing scientific data on image quality, and many VDTs on the market do not provide the legibility of high-quality printed material" (p. 2). It has been estimated that nearly half of all VDTs now in use are improperly designed for intensive office use (Snyder, 1983). After 1500 hours of usage, a CRT is about half as bright as when new. The stroke thickness of characters is somewhat reduced and the apparent brightness of the display is diminished. Contrast and luminance controls can compensate for this aging, although some displays are not so equipped. Few suppliers make efforts to inform users of these maintenance and replacement requirements (Snyder, 1982). It appears highly probable that under certain conditions, the poor image quality of some VDT screens could contribute substantially to visual problems, especially when prolonged, intensive screen viewing is required.

Illumination. The third recognized risk factor is the illumination of the environment. Four basic problem areas have been identified: illumination level, reflections, glare and contrast.

Illumination level. Prior to energy conservation concerns, there was a tendency to believe that the more light there was, the better the environment would be for office work. As a result, many offices are currently overlit or too bright for certain activities. This is a particular problem in VDT offices. Increasing the light level, up to a point, improves contrast and visibility for most office tasks. However, VDTs emit their own light, and high illumination levels actually reduce the contrast and visibility of the screen image. Thus, while current recommendations for general office lighting are usually around 100 foot-candles (1000 lux), it is frequently suggested that the level be reduced to about 50 foot-candles or less for screen-based work (500 lux). An alternative recommendation is to provide even lower levels (30-40 foot-candles, 300-400 lux) while providing supplementary task lighting for other non-VDT work. Techniques for reducing illumination levels are readily available and a variety of suitable task lights have been marketed.

Reflections. Light reflected from objects within the field of view can cause discomfort and annoyance, and degrade performance. Shiny desk surfaces and keyboards are potential sources but some of the most serious problems are caused by reflections from the surface of VDT screens. A variety of control methods are available. One of the simplest is repositioning the VDT screen in relation to light sources. Room partitions, hoods or barriers may be placed between the screen and the source. Windows can be covered with venetian blinds, louver drapes, or shades. Special baffles, louvers, diffusers and refractors may be installed directly on luminaires. Many of these devices can be effectively retrofitted to existing systems at reasonable costs. Treatment of VDT screens may also be effective and is most appropriate where little control can be exercised over general environmental lighting conditions. This involves the use of a variety of surface coatings, treatments or filters to reduce reflections. While many VDT manufacturers now include some of these devices, the practice is by no means universal. One filter manufacturer reported that they supply 50,000 filters per month to VDT manufacturers (Sunflex, 1983). Filters can cost between $40 (micromesh) and $100 (circular polarized) each. One filter which is sold to an end user for $55, would cost the manufacturer $10 plus the cost of installation (Sunflex, 1983). The major disadvantages of manufacturer installation are potential reductions of image quality and the observation that the environment often determines the need for, and the most effective filter.

Glare. Discomfort and disability glare appear to be among the leading sources of discomfort. The sensation of glare is related to the intensity, size and location of the source as well as the background luminance or "light" level. Since the primary sources of glare in offices are windows and luminaires, jobs which require the individual to look forward rather than down are more likely to subject workers to such discomfort. Thus typists to some extent and even more so VDT operators are likely to encounter glare.

Glare control methods are very similar to those described for reflection control and include reducing the size, intensity and location of potential sources of glare within the environment.

Contrast. Another VDT specific problem relates to the positive contrast screens (light characters on a dark background) which are used in most terminals. Since VDT jobs often require alternating between white source documents and the darker screen, it has been suggested that the required continuous changes in the pupillary and retinal adaptation of the eye could lead to fatigue. There is, however, very little data available to evaluate the contribution of this factor to visual complaints. Research has not yet demonstrated any significant difference between negative and positive contrast screens. It should also be noted here that no particular screen or image colors appear to offer any particular advantages in terms of reducing eye complaints. It has been noted that the simultaneous use of colors from extremes of the visible spectrum (e.g. reds and blues) should be avoided since the eye cannot focus on both at the same time.

It appears unquestionable that illumination problems can play a significant role in contributing to visual complaints. While the application of conventional lighting design principles has generally lead to acceptable lighting in most traditional offices, the introduction of VDTs has necessitated the reconsideration of many accepted principles. Three unique characteristics of VDTs can be identified as important determinants of lighting design: the vertical orientation of the screen, the reflectance of the screen surface, and the light emitting nature of the display. Thus, it has become more difficult to design office lighting systems and office layouts and greater demands are being made on designer. While it is potentially feasible to design offices for VDT use, in most cases the problem involves adapting the existing environment to the new task. While the technology for accomplishing such control in a reasonably adequate fashion is readily available (and generally at acceptable costs), the problem seems to lie in the lack of widespread understanding of lighting principles and associated visual discomfort as well as in the proper application of available techniques. Many users depend upon vendors rather than lighting engineers for expertise and technical assistance. The appropriateness and cost effectiveness of various solutions depends upon an understanding of the nature of complaints. This will vary considerably depending upon the environment, the equipment and the job. As a result, no single control method can be expected to solve all problems and site-specific approaches are usually required.

Air Quality. The quality of air must not be overlooked as a contributor to certain types of eye irritation. The eyes are particularly sensitive to air contaminants including dusts, chemicals and allergens as well as low humidity. Very few studies of visual problems in offices have given consideration to air quality. The Canadian Labor Congress study (1982) results do indicate that those VDT operators who are bothered by dry air are more likely to report visual problems. The relationship was comparable in magnitude to the effects of poor lighting, and possibly stronger than the effects of other variables including hours on the VDT, frequency of breaks, time spent in screen viewing, flicker perception and a number of other variables. Extremely dry air may cause ocular irritation by interfering with lacrimation which may cause distress, especially for contact lens wearers. At humidities below 10-15%, corneal hypoxia may cause epithelial damage and edema.

Job Pressure and Stress. The functioning of the visual systems, and in particular the focusing apparatus of the eye, is affected by the level of stress experienced. While reported job pressures may be related to the visual demands of the job, the relationship between visual function and stress deserves further study.

Summary. Reducing the incidence of visual problems requires an understanding of all potential contributing factors including the visual demands of the job, the quality and clarity of viewed materials and the lighting conditions present. It is very likely that each of these factors plays some role in the development of visual problems and in many cases there may be interactions between factors. For example, an individual who experiences visual problems due to the demands of the task may then become more sensitive to adverse lighting conditions. Other factors including air quality and stress must not be overlooked.

Job Demands

Physical Demands. Excessive physical demands lead to fatigue. The physical demands of most office jobs are generally considered to be minimal at least in comparison to industrial jobs. The importance of constrained working positions must not be overlooked, however. Workers whose jobs require them to sit in one location for extended periods can be expected to experience muscular fatigue and pain. Maintaining a fixed posture places static loads on postural muscles. It is well-established that static loads must be limited to a maximum of 10% of muscle capacity if fatigue is to be avoided. In contrast to the dynamic muscular work associated with activity, the supply of oxygen is restricted and waste products are not removed. The result is rapid fatigue and muscular pain. Awkward or poor working positions tend to increase the load on muscles and greatly accelerate the fatigue process.

Thus, while good working posture with adequate support of the back, legs, head and arms will delay the onset of fatigue, movement is also necessary to alleviate the fatigue and pain associated with constrained positions. Any workstation design then will result in fatigue unless workers can actively compensate for static loading with changes of position and posture. The same phenomena has been suggested as a possible contributor to eyestrain among those who must focus on work at a fixed distance for extended periods of time.

Exercise has been one solution offered to prevent fatigue and would appear to be a reasonable one. Unfortunately, the time spent exercising is viewed as lost productive time and, therefore, is often not viewed favorably by employers. More frequent rest breaks during which the worker is allowed to move around offer similar advantages. The required frequency of rest breaks will depend upon the extent of postural constraint inherent in the job.

Variations in work tasks and working postures are often more acceptable techniques. It has frequently been pointed out that the introduction of office automation has led to simplification and increased repetitiveness in jobs resulting in greater postural constraints. While this hypothesis is difficult to document it is not an unreasonable one in view of the efforts of industrial engineers to increase productivity through the application of scientific management principles to office work. The promises and premises of these techniques may, in fact, often be counterproductive and must be carefully evaluated in light of their potentially adverse impact upon health and well-being.

Another potential solution which has been applied with some success involves designing workstations which allow variations in work position. While it is unlikely that minor variations in workstation position will successfully prevent fatigue, innovations such as stand up workstations may be helpful. It is a well-recognized fact in industrial ergonomics that workstations which allow alternating between sitting and standing are the most desirable.

Mental Demands. The demands of work which require continuous mental attention are particularly difficult to evaluate. Virtually all office jobs require mental activity whether it is simple and repetitive (data entry) or requires extensive decision making. Unlike physical workloads where the demands can be measured in terms of input parameters such as forces or weights and outputs such as cardiopulmonary responses or energy expenditure, there are no clear measurement techniques for evaluating mental workload. Furthermore, different dimensions contribute to the stressfulness of the mental work. At one extreme the job may require continuous attention with little decision making which leads to boredom. In prolonged continuous mental work, performance, especially of short-cycled repetitive tasks, becomes slower, more irregular and more prone to errors. Degradation of performance may occur within 30 minutes. Attention lapses and mental blocks become more frequent and are accompanied by feelings of frustration. Most of these performance changes can be attributed to losses of attentiveness, which can be deferred through introduction of rest breaks or alternate tasks. At the other extreme, the job may place excessive demands on critical evaluation or decision making abilities which also lead to stress and fatigue.

Performance, measured in terms of quality, errors, or quantity of work, is commonly used to evaluate mental activity. In many cases work performance is a very poor indicator of stress and fatigue since the worker is able to call upon reserve capacities to handle increased loads, and as a result no performance decrements may be observable. This is especially true in situations where workers are highly motivated due to inherent job interest, financial rewards, other social pressures or fears of jeopardizing their position. If reserves are continuously called upon, exhaustion eventually sets in, although it may not be evident until after the work shift. Under these circumstances, workers are less able to deal with other sources of irritation. It has been commonly observed that the tolerance for problems such as noise, poor chair design, glare, air quality, etc. are lower in mentally demanding jobs.

The only effective ways to directly control these problems are by reducing demands, utilizing more frequent breaks, and providing a variety of tasks (some requiring physical rather than mental activity). A frequent criticism of work simplification in automated offices is that it results in the removal of a variety of the more physically active and less mentally demanding tasks which usually accompany traditional office work (e.g. filing, copying, and telephone answering). The application of scientific management techniques to increase productivity frequently does not take into consideration the potentially adverse impact of removing these tasks from the job.

Summary

Increasing attention has been given in recent years to the way in which the job fits the worker. These ergonomic considerations have been stimulated by growing concerns over the potential adverse health effects of operating VDTs. These problems are in no way limited to VDT work. It does appear, however, that as a group, those who work at VDTs do encounter such problems more frequently than many other work groups. There are several possible explanations for this observation. First, there may be something inherent in the design or use of VDTs, although close examination of currently available data do not support such a conclusion. Secondly, those who use VDTs have not given adequate attention to the environment into which the equipment is introduced. In this sense, VDTs are unique since they do change the design requirements of both the workstation and the environment. Third, the introduction of VDTs has in many cases been accompanied by changes in jobs which have increased physical and mental demands on workers. The last two explanation are supported by research and observations.

Control strategies are available which can effectively reduce the ergonomic stresses associated with office work. These include improvements in the equipment, workstation, environment, and job design. In most cases, all will have to be used to some extent to effectively control problems.

Two major obstacles stand in the way of implementing these controls, however. The first involves the lack of definitive data which clearly establish the relationship between particular stressors and the resultant strain. It is, therefore, difficult to establish before hand the cost effectiveness of different control strategies. The second obstacle is the lack of understanding of problem sources and controls by those who purchase equipment and those who use it. This has been an obvious problem in offices where VDTs have been introduced. Conflicting claims and oversimplification of solutions coupled with limited understanding on the part of purchasers and users makes the application of existing knowledge and technology more problematic than might be expected. While many manufacturers of office furniture provide well-designed products, the claims of some that their equipment is designed using principles of ergonomics or human factors do not stand up to scientific scrutiny. In many cases, the selection of furniture and the design of the environment are highly specific to the task. While good design guidelines for specifying VDT display characteristics such as luminance, contrast, flicker, polarity, color, raster structure, jitter and temporal instability, font and character formation, it is difficult for manufacturers, purchasers and users to make comparisons between products because techniques for measuring and evaluating image quality have not been standardized and applied. The National Research Council (1983) recommended "that efforts be made to standardize measurement techniques" and that "Characteristic measures of products should be made routinely available to purchasers and user" (p. 3).

A variety of over-simplified approaches to dealing with ergonomic problems in the form of guidelines, standards and recommendations have been generated in the past few years. In practice, it is generally found that these approaches are of very limited use in solving the complex systems problems involved in the design of work and work environments. The wide variety of new products also offers consumers increased choices although access to these products still remains a problem. Correct choices also depend upon consumer understanding of ergonomic principles.

It has been suggested by some that adequate knowledge and information currently exists to solve the ergonomic problems encountered in modern offices. Such statements indicate a lack of understanding of the complexity of problems and the difficulties involved in abating problems. Future technological advances and applications may simplify these problems in some cases (e.g. flat panel displays) or complicate them further (e.g. voice communication, touch panels).

Temperature

One of the single most common sources of complaints from office workers concerns climatic conditions including temperature, humidity and air movement. While there is some individual variability in preferences for climatic conditions, survey data indicate varying levels of perceived discomfort are reported by many if not most persons in offices. A survey of 1004 office workers (Harris, 1980) reported that 55% considered the temperature in their workplace uncomfortable. There were no age differences although females more frequently reported uncomfortable temperatures. Forty-one percent of all workers indicated that their most recent complaint concerned room temperature and 37% of the entire sample indicated that they used portable heaters or fans. Fifty percent of 203 office executives interviewed indicated that temperature improvement for their employees was one of their most important needs. While these data were collected during the period in which regulatory standards for energy conservation were in effect, other studies not affected by this constraint have reported similar findings. Table 2-6 present the results of several studies on temperature.

The clinical symptoms caused by temperature influences include fatigue, headache, sweating, respiratory discomfort and changes in pulse frequency. While both temperature and air circulation can affect the distribution and build up of air contaminants and thereby affect health, there do not appear to be any serious health consequences related to the temperature variations normally encountered in office environments. Measures of general well-being, job satisfaction and psychological stress are most pertinent and informative in evaluating the health consequences of uncomfortable temperatures. While there are large individual differences in thermal comfort preferences, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), a private standard setting group, has developed a voluntary consensus standard (ASHRAE 55-1981) which includes acceptable ranges for thermal comfort, meant to satisfy 80% of the average population. It specifies: (1) a range of 73°-79°F for the average clothed individual in the summer and a range of 68°-74.5°F in the winter, (2) relative humidity between 30-60% year round, and (3) an average indoor air velocity between .15 and .25 m/sec. Thermal comfort is affected by many things including the combination of air temperature and radiant temperature, air velocity, typical clothing, level of muscular activity, metabolism, and circadian and diurnal cycles. Thus, a constant temperature will at times be uncomfortable for the same individual.

TABLE 2-6

Frequency of Reported Temperature Related Problems

	Percent Reporting Problems		
	Heat	Cold	Dry Air
Canadian Labour Congress, 1982 (n=2330)			
VDT	19	23	45
Non-VDT	20	18	37
Harris, 1980 (n=658)			
Office workers			
Summer	37	13	
Winter	14	39	
Sauter et al., 1983 (n=333)			
VDT operators (summer)	25[1]	6[1]	
Non-VDT workers (summer)	24[1]	3[1]	
	Uncomfortable[2]		
Arndt, 1980 (n=987)			
Telephone operators	72		
Service assistants	71		
Accounting clerks	65		
Harris, 1980 (n=658)			
Clerical	61		
Secretarial	55		
Professional	49		
Executive, managers, administrators	48		

---

[1] Includes only those reporting temperatures "much to high" or "much too low"

[2] (Arndt, 1980) Percent reporting uncomfortable or very uncomfortable temperatures
(Harris, 1980) Percent reporting temperature was not right

Despite this proliferation of variables, certain critical factors can be identified which will usually lead to unpleasant sensations. For example, local areas of temperature change such as vertical temperature gradients greater than 5°F, and radiative asymmetries exceeding 9°F in a vertical direction or 18°F in a horizontal direction will be experienced as uncomfortable. Thus, sitting within 4-5 feet of a glass wall on a hot or cold day may be uncomfortable regardless of the room temperature. Sitting near heat producing equipment such as VDTs, copiers and lighting may also lead to discomfort.

Most offices use a central mechanical ventilation system which creates an integrated building system. Consequently, the climates of individual rooms become interdependent. Changes in activities, or additional personnel or equipment in one room will result in an imbalance in that location or elsewhere which may not be easily corrected.

Ventilation during heating and cooling seasons is usually provided by the same system, which can create problems since the air movement and mixing of heated air is different than that of cooled air. Furthermore, in a cool or neutral environment, air movement may be felt as uncomfortable, while increased air movement in a warm environment is desirable and extends the comfort zone to higher ambient temperatures.

Some of the control measures available are well-established and readily available. One of the most straight forward is an adequate and accurate assessment of the factors which affect discomfort. As indicated above, these factors may result in unequal temperatures throughout a building or even within a single open office area due to the placement of windows and heat producing equipment. The addition of portable room partitions, interior surfacings or fixtures can also effect the ventilation of certain work areas.

This problem could be alleviated somewhat by the expected introduction of systems furniture with integrate ventilation ducts.

Too often, individual complaints are considered to be indications of personal differences and, therefore, are thought to be beyond the control of office managers or building maintenance engineers. It is, however, well-established that temperature perception is directly related to the actual effective temperature, suggesting that greater attention to temperature and ventilation variations could significantly reduce discomfort. When individual preferences do vary, careful assessment and judicious selection of work areas to accommodate individuals can often solve problems.

While detailed design standards for heating and ventilation exist, they admittedly are not based entirely upon hard scientific data but often on the judgment of "experts". In addition, design standards indicate how a system is supposed to operate, and the actual performance of the system can vary considerably due to design errors, changes in occupancy or activity, addition of equipment or partitions, and improper or inadequate maintenance. Continuous attention must be given to these problems by management.
One of the obstacles to providing a comfortable climate is the difficulty associated with making accurate and detailed measurements, which building engineers are neither equipped or trained to perform.

The primary advantage of providing a comfortable climate (beyond improved comfort and well-being) relates to improved productivity. It is clear that productivity can be adversely affected by uncomfortable temperatures (Fanger, 1979). Both employees and executives appear to be convinced of this fact (Harris, 1980). The principle causes of commonly encountered problems would, therefore, appear to be the lack of attention, inadequate information and limited resources for making corrections.

Humidity

Humidity problems in offices can contribute to a number of adverse health outcomes. While very little data concerning actual humidity levels exist, it can generally be observed that very few office HVAC systems include any method of controlling the level.

It is generally believed that dry air leads to chronic irritation of the nasal and bronchial passages. Often noted is desiccation of the mucous membranes of the air ducts which could obstruct the flow of mucous over the ciliary tracts, resulting in a diminished resistance to infection. These medical interpretations have been confirmed by several studies. The potential significance of the problem must be considered in light of the fact that respiratory problems are the leading cause of restricted activity in the U.S., averaging about six days per person per year. A number of studies have demonstrated that increasing humidity is associated with decreasing absenteeism (Green, 1982). It has generally been concluded that humidities of 40-50% are desirable, and below 30% they become unhygienic. It has also been reported in a number of cases that outbreaks of skin rashes were related to humidities below 30-40° (White and Rycroft, 1982; Rycroft and Smith, 1980). Raising the humidity above 45% effectively eliminated these problems.

Extremely dry air may also cause ocular irritation by interfering with lacrimation which can cause distress, especially for contact lens wearers. Corneal hypoxia with very low humidities (e.g. 10%) can cause epithelial damage and edema. Dry air must be considered as a more serious risk factor in jobs which have high visual demands, since it may exacerbate the frequently reported complaints of eye problems in such tasks. For example, the Canadian VDT study (CLC, 1982) reported a strong direct relationship between complaints about dry air and eye irritation. In fact, the relationship was as strong as any other variable, including illumination.

Low humidity may be a special problem around certain electronic equipment due to heating effect which act to reduce the relative humidity close to the equipment. Low humidity and static build-ups near VDTs have been implicated as causes of facial rashes in a small number of medically documented cases (Linden and Rolfsen, 1981).

Studies at the ASHRAE Research Laboratory have indicated that odor perception and irritation due, in particular to cigarette smoke, are lowered with higher relative humidities (Kuehner, 1956). While the perceptible odor level of cigarette smoke decreases with exposure time, irritation to the nose and eyes generally increases. The irritation is greatest at low relative humidities. ASHRAE (1981) recommends a minimum of 45% relative humidity to control odor perception and irritation.

High humidities (above 50%) do not appreciably improve health conditions and may lead to other problems including equipment damage, condensation, and growth of micro-organisms.

Relative humidity does not appreciably affect thermal comfort if the temperature is maintained within a reasonable comfort range (73 to 78°F). As the dry-bulb temperature increase above 78°F, humidity effects becomes very important as evaporation becomes the major source of heat loss. An increment from 30% to 70% provides about the same change in thermal sensation as a one degree centigrade increase in temperature. It is, therefore, much more economical to control air temperature to attain thermal comfort.

ASHRAE 55-1981 recommends a relative humidity between 30% and 60%. A variety of humidification systems exist, although the selection and application of equipment involves consideration of both the environmental conditions of the occupancy and the characteristics of the building. Humidification may be costly and difficult with certain types of non-central HVAC systems, and should be a factor in selection of systems in new buildings.

Air Quality

Concerns about indoor air quality have been a topic of increasing concern in recent years. Some of the attention can be traced to heightened public awareness of the importance of air quality and more recently to the appearance of the general topic of indoor pollution of homes, public buildings and offices. Energy conservation measures (reduced ventilation and "sealing" of buildings) initiated in recent years, have in some cases contributed to the seriousness of these problems. Energy conservation efforts have often been blamed for the increasing number of complaints about "sick building syndrome" or "stuffy office syndrome." Although there is some truth to these claims, the actual situation is considerably more complex. For example, where outdoor air quality is low, energy conservation measures may improve indoor breathing air quality.

Other factors which may have contributed to increasing office air quality concerns have risen out of general public awareness. Some publicity has been given to reports of the adverse health effects associated with passive cigarette "smoking," asbestos in buildings, formaldehyde gases from urea formaldehyde foam insulation, radon decay products, and public health indoor air disasters such as the outbreaks of Legionnaires disease in 1976, and the state office building fire in Binghampton, N.Y., in 1981 in which toxic soot containing polychlorinated biphenals contaminated the building.

In general terms, there is a large potential for generation of office air pollution from occupational activities, use of equipment, chemicals, the wear and tear and outgassing of some structural or decorative materials, the influence of thermal factors and intrusion of outdoor pollutants.

In order to systematically evaluate risks, one must examine the number of individuals exposed, the severity of exposure and the consequences of exposure. Unfortunately, there is a noticeable lack of information available on all of these questions. Accurate assessments of risk are, therefore, very difficult to develop and estimates must be made on the basis of anecdotal, incidental or otherwise limited reports of exposures or health problems. In many cases, objective verification of the direct causes of symptoms is difficult, even when severe. It has been suggested that in some cases in the occupational health literature, an inability to detect or determine direct causal links has sparked the conclusion that observed symptoms are psychogenic in nature ("psychogenic contagion reactions," or "mass hysterical reactions") (Faust and Brilliant, 1981).

Number of Office Workers at Risk

There are remarkably few accurate assessments available concerning the number of people at risk, both with respect to health outcome and symptom report data in investigations of offices. The National Institute for Occupational Safety and Health has conducted more than 180 indoor air quality investigations since 1978, most in response to worker complaints of eye, nose, and throat irritations; headaches; skin rashes and fatigue. (Occupational Hazards, 1983). The New York City Department of Environmental Protection reported receiving 98 complaints in a 7 month span related to both residential and workplace sources of indoor pollution (Ferrand and Moriates, 1981). Such data only suggest there are problems but do not allow any estimates of the total number of persons exposed.

The data concerning health symptoms or potential hazards related to office work (even self-reported survey data) are also scarce and are difficult to assess in any case. Symptoms are not always associated with workplace exposures, sometimes lack consistency between individuals, and human sensory systems do not always provide sufficient detection capability to gain infallible signals about the safety of the environment. One example of available survey results comes from the report of an office workers advocacy group (Gregory, 1981). Of those office workers completing the survey, 40% indicated they "had no fresh air" and 25.4% reported exposure to irritating fumes. Unfortunately, the survey response rate was exceedingly low (less than 9%) which unfortunately introduces strong possibilities that persons answering were not "typical". An industry sponsored study of office workers (Harris, 1980) (which does not report response rates), found that 30% of the office workers interviewed thought their office was "too stuffy". While most individuals worked where unrestricted cigarette smoking was allowed (94%), only about 1/3 were regular smokers. Of the nonsmokers, 26% said they were bothered a great deal, 17% somewhat, 11% hardly at all, and 43% not at all by the smoke. It is not possible to ascertain from the data whether ventilation was adequate, work locations were widely separated, or workers simply weren't "bothered".

In another study of over 2300 office workers (response rate 81%) from 15 different offices, it was found that 57% reported "poor" or "very poor" air circulation in their offices (Canadian Labour Congress, 1982). Table 2-7 indicates the frequency of reported problems from three studies.

TABLE 2-7

Frequency of Reported Ventilation Problems

	Percent reporting inadequate air circulation
Harris, 1980 (n=658)	
Clerical	40
Secretarial	22
Professional	29
Executives, managers, administrators	35
Canadian Labour Congress, 1982 (n=2330)	
VDT	35[1]
Non-VDT	29[1]
Professional/administrative	17[1]
Arndt, 1980 (n=987)	
Telephone operators	54[2]
Service assistants	37[2]
Accounting clerks	43[2]

---

[1] Percentages reported indicate only those indicating ventilation was "very poor"
An additional 24% of all those surveyed indicated ventilation was "poor".

[2] Percent reported very uncomfortable or uncomfortable.

Severity of Exposures

While data on exposure levels in offices are again limited, The National Research Council's report on Indoor Pollutants (1981, pp. 11-12) concluded "... there is direct and circumstantial evidence that human exposures are large enough and common enough to account for substantial morbidity and premature mortality." These exposures can be substantial in unusual circumstances and can, in some cases, exceed ambient outdoor air quality standards. Generally, however, reported concentrations of indoor air contaminants are quite low. For example, of 15 office health hazard evaluations reported by NIOSH between 1980 and 1981, only 3 cases involved unacceptably high concentrations. In each case the exposures were related to specific sources in specific locations (NIOSH HHE reports, 1980-81, 1982). A survey of 30 offices by the Bureau of Chemical Hazards of the Ontario government found that the levels of all identified compounds (volatile organics) were well below their respective ACGIH, 8-hour TWA-TLV values (Otson, et al., 1983). Other studies have reported similar findings. After collecting air samples within four offices in which occupants had complained of dizziness, drowsiness, inability to concentrate, stuffiness, and general poor air quality, Miksch, et al. (1982) concluded that ... "relative to outdoor air, the concentrations of a variety of organic solvent vapors generated within and contained by the built environment are high. When compared with concentrations recommended for protecting the health of workers in industrial environments, the concentrations of individual organic chemist contaminants are lower by 2-4 orders of magnitude. The additive exposures, expressed as the sum of the percentage ratios of individual organic chemical contaminants to their recommended exposure levels, does not exceed more than a few percent" (p. 136). Since most Americans spend 80-90% of their time indoors, even low level exposures may make substantial contributions to time weighted exposures, however. Many of the air pollutants found in office environments are also found in the home.

Health Consequences

At high concentrations, indoor air contaminants may cause irritation of sensitive tissues. illnesses, and death from acute as well as chronic exposures. Epidemiological data concerning the incidence or prevalence of adverse health effects is lacking and many of the conclusions about potential effects must be drawn from studies performed in other environments or carried out under controlled conditions. For example, the adverse health effects of exposure (even at low levels) to such contaminants as asbestos, formaldehyde and tobacco smoke are well-documented. Often overlooked and less well-researched are the effects of airborne viruses and bacteria. Other substances can also lead to adverse effects on health but apparently only after prolonged or repeated exposure. These contaminants include substances that accumulate in the body, substances that cause relatively little harm to tissue with a single exposure but produce cumulative effects if exposure is repeated, and infectious agents which are more likely to cause health problems if exposure is repeated. Other airborne materials may cause sensitization phenomena in selected individuals which can later result in reactions of greater severity occurring at very low exposure levels.

Many substances appear to act primarily as irritants at low exposure levels by inducing local inflammatory reactions in the eyes, nose, lung or other sites, but the long term and synergistic effects of chronic exposure are largely unknown. While the discomfort associated with low level exposures to dusts, gas, vapors, allergens or odors obviously affect general well-being, cumulative exposures to polluted air may also act as a source of stress.

It is impossible to determine with any certitude the economic burden associated with increased health care, lost work time, lost production and turnover which may be associated with polluted air.

Sources of Air Pollution in Offices

It is beyond the scope of this report to identify all of the potential sources, effects and exposures to air contaminants in office environments. The general categories of contaminants are listed in Table 2-8.

Control Strategies

There are five basic control strategies that can be used to reduce exposure to indoor air contaminants: (1) ventilation, (2) source removal, (3) source modification, (4) air cleaning, and (5) education and behavior change.

Ventilation. Concentrations of contaminants are often reduced by local exhaust at the source or by dilution of the contaminant with fresh or clean air.

Source Removal. Sources of hazardous substances may be removed or less hazardous materials may be substituted.

Source Modification. Emission rates may be reduced through engineering modification of equipment processes, changes in equipment use practices, or contaminants may be contained by a barrier or sealant.

Air Cleaning. Air contaminants can be removed from air by a number of different devices or processes, often within ventilation systems, before air is recirculated.

Education. Information concerning the contents and hazards associated with various products and materials, the characteristics of equipment operation or product uses which contribute to emissions, and training concerning

TABLE 2-8

Examples of Types of Air Containment Exposures in Offices

Contaminant	Standard	Exposure Levels	Examples and Sources
Micro-organisms, allergens	None	Potentially high	Bacteria, viruses, fungi; contamination of humidifiers and air conditioners can cause disease, fever, infectious lung diseases, hypersensitivity pneumonitis. Allergens cause sensitization in some individuals.
Organic chemicals	Exist for some chemicals	Typically low, below TLV for individual chemicals	Sources include building materials, consumer products, tobacco smoke, building maintenance products, wet process photocopiers, and bioeffluents. Formaldehyde is one of the most serious.
Gases	Some standards exist	Typically below existing standards	Cigarette smoke, outside sources, combustion processes, and equipment are potential sources of gases, including carbon monoxide and ozone.
Asbestos	OSHA standard	May exceed standards when disturbed	Disturbances of insulation and building materials due to removal, renovation, maintenance work and care may produce high levels. Natural deterioration of surface may lead to contamination of air supplies.
Tobacco smoke	None	Potentially high levels	Passive smoking has been implicated as a contributing factors in certain instances of cancer, cardiovascular effects, and respiratory effects. Asthma and allergic rhinitis patients are especially vulnerable to irritant effects.
Other sources	None applicable	Typically short exposure, potentially high brief exposures	Numerous other office products such as glues, cleaning solvents, deordorizers, correction fluids, and coloring pens are potential sources of episodic exposure to air contaminants as well as skin contact.

safe handling can be provided to workers. This allows individuals to take steps to avoid or limit exposures.

Application of Control Strategies

While adequate control of indoor air pollution is technically feasible, since well-established methods are clearly available, the major problem appears to lie in selection and design of the appropriate strategy for specific situations and substance combinations. Source removal, source modification, isolation, and air cleaning can be effective controls, but all require that the source be identified. Identification and quantification of air contaminants which appear to be causing complaints are often very difficult due to the low exposure levels usually involved and the lack of adequate information concerning what exposure limits must be achieved, especially when several substances are involved.

Education of employees, especially concerning the use of office products and associated hazards, depends largely upon accurate and complete product information, labels, and warnings which are often unavailable. Market forces can provide a potentially powerful influence on the availability of such information although this has generally not occurred, and governmental intervention can result in more valuable and widely available information. Thirteen states and 35 cities and counties have adopted "right to know" or "hazard communication" legislation (New York Times, 1983). OSHA has promulgated a standard but it is not as strict as most state laws and affects only employers in the manufacturing sector. It is unclear whether the federal standard will preempt state and local laws.

The primary method of controlling air contaminants in most buildings is general ventilation. The quality of air provided by ventilation depends directly upon the amount and quality of fresh outside air added (or quality and proportion of recirculated filtered air) and the air mixing capabilities of the system. Fresh outside air is added through the ventilation system, by natural ventilation into the building (e.g. doors or windows), and by infiltration through building structures or surfaces.

Energy conservation efforts have concentrated on reducing the amount of outside air drawn into interiors to a minimum since such air must be conditioned before entering the system. Thus, sealing of buildings and reductions in ventilation can have significant effects on air quality. Air mixing is affected by a number of building air system factors such as the ventilation rate, thermal factors, air diffuser design and placement, air velocity, obstructions and occupant activities.

Most ventilation systems are designed to meet specific design standards established by state or local building codes. The American Society of Heating, Refrigeration, Air Conditioning Engineers (ASHRAE), a private standard setting professional organization has developed specifications which are often incorporated or referenced in these codes (ASHRAE 62-73 or the revised ASHRAE 62-1981). Unfortunately, ventilation specifications and design do not guarantee adequate dilution or removal of contaminants during actual system operation in specific buildings or particular building areas. ASHRAE 62-198 only specifies minimum air exchange rates and provides numerical limits fo maximum indoor air concentrations of a variety of pollutants including tobac o smoke. The recommended design concentrations in 62-1981 Appendix C are one-tenth of the TLV guidelines. In practice, the specifications are used during the ventilation planning stages for new or remodeled buildings. Since there are no performance standards, there can be no guarantee that the system operates as it was designed or that individual exposures will be adequately controlled. Local modifications including closing of vents, changes in types and settings of diffusers, sealing of buildings, placement of wall partitions; as well as inefficient filtering, reductions in make-up air and thermal factors all effect the performance of the ventilation system. There is virtually no field enforcement of standards related to ventilation system performance in operational systems. Furthermore, quantitative air systems performance evaluation is expensive and elaborate. Routine gathering of detailed ventilation and contaminant measurements is beyond the capability of most building staffs. The resources and information available to building maintenance and engineering personnel do not presently allow changes in this state of affairs. The scope of the problem is indicated by observations made in federal facilities by building inspectors who noted that "outside air in many buildings is reduced to zero" in spite of the fact that federal regulations suggest a 10% recirculation rate (Repace, 1981).

Research Needs

It is readily apparent that more research is necessary to determine sources and distributions of air contaminants, exposure levels and associated health effects (especially at low levels), potential synergistic effects, and populations at risk. Methods for examining the quality of air reaching each office occupant rather than total ventilation rates must be established. Mixing and dispersion of contaminants from sources in rooms have not been extensively investigated. Research is also necessary to establish the most effective and economical control strategies. ASHRAE believes that once this research has been carried out the market can then respond with improved, innovative and cost-effective solutions (ASHRAE, 1982). There is little evidence, however, that public perceptions of the direct, indirect and social health costs associated with indoor pollutants are of sufficient depth or breadth to alone affect markets substantially in the near term, or probably, the foreseeable future.

Information presented at recent subcommittee hearings (August, 1983) of the House Committee on Science and Technology indicated that federally supported research on indoor air quality has been minimal in recent years. At least four agencies (Environmental Protection Agency, Department of Energy, Health and Human Services, and Consumer Product Safety Commission) may share some responsibility for such research. EPA indicated they had no regulatory authority and had no need to perform indoor air research, and requested no funding for FY84. DOE likewise requested no funding. Both were appropriated funds by Congress, however (Hileman, 1983).

Economic Considerations

In addition to the obvious potential health effects, other factors including discomfort, decreased productivity, lost work time, the soiling and corrosion associated with contaminants and increases in maintenance and housekeeping must be considered in evaluating the benefits of reduced air contamination. The primary cost factor is energy. Heat exchangers which conserve energy without reducing ventilation rates, substitution or removal of contaminant sources, emission reduction techniques, and air cleaning devices are relatively inexpensive methods of controlling air contamination which have not been adequately utilized and which do not effect energy costs as much as increasing ventilation. Other techniques such as periodic purging rather than continuous mixing with outside air may prove economically beneficial (Meyer, 1983). Adaptation of passive air sampling techniques to clean air is also attractive from the standpoint of operating energy economy (Billings and

Vanderslice, 1982). In many cases, merely training maintenance personnel in basic techniques of optimizing existing system operational capabilities from air quality, energy and human factors standpoints simultaneously, can yield substantial gains with little further resource expenditure and often with cost savings.

Ultimately however, it would be most desirable and efficient to be able to determine ventilation and control requirements based upon adequate knowledge of contaminant levels and their associated health effects.

Noise

Noise in offices seldom reaches levels which would impair the hearing of a substantial number of people although in certain situations levels in access of 80 dBA can be reached which will affect the hearing of some individuals. Noise of this intensity could, for example, be associated with office equipment placed very close to workers. High speed printers are one such source of noise. Working in small enclosed areas with a number of pieces of equipment will exacerbate the problem.

More common, however, are noises which are irritating, affect performance, or generally cause stress. Table 2-9 summarizes the results of several studies which have asked individuals about noise in offices. The most frequent source of irritating noise is conversation. Most susceptible are those performing work requiring concentration. Telephone conversation also becomes difficult. Traditional "bull pen" and open plan offices are particularly likely to lead to this type of problem, the latter due to the fact that partitions or panels often do not go up to the ceiling and sometimes not to the floor. Some workstations are enclosed on only two sides. Telephones, office

TABLE 2-9

Self-Reported Noise Problems in Offices

Study	Percent reporting noise problems	
	Much too high	Somewhat high
Sauter et al., 1983 (n=333)		
VDT operators	14	44
Non-VDT workers	20	54
	Too noisy	
Canadian Labour Congress, 1982 (n=2330)		
VDT	54 (varies by job, 11%-72%)	
Non-VDT	39 (varies by job, 26%-48%)	
	Do not have quiet	
Harris, 1980 (n=658)		
Clerical	53	
Secretarial	42	
Professional	49	
Executive, manager, supervisor	30	
(n=853)		
Conventional office	37	
Bull pen office	71	
Open office	50	
	Uncomfortable	Very uncomfortable
Arndt, 1980 (n=987)		
Telephone operators	49	20
Service assistants	51	13
Accounting clerks	49	18

machines and activities of other workers are sources of distraction for the same reasons.

Other sources of irritating noise include office equipment and ventilation systems. Some electronic devices emit high frequency (low level) sounds which can be particularly irritating.

In many cases, irritating and distracting noises are described as a source of stress. The commonly experienced displeasure with sounds such as a dripping faucet or chalk scraping on a blackboard serve as clear examples. Conversational noise can act as a stressor by interfering with attention or performance.

Noise is known to cause certain nonauditory effects such as vasoconstriction of small blood vessels, changes in blood pressure, decreased respiration rate and increased muscle tension. These may simply be manifestations of a generalized stress response. The long term effects of such response are unclear. Reported affects have usually been associated with fairly severe exposures.

The speech interference, distraction and irritation caused by noise are dependent upon the loudness, the frequency, and the temporal characteristics of the noise. Ordinarily, higher frequencies cause more problems, both in terms of irritation and speech interference. Conversation becomes difficult at levels above 55-65 dBA (depending upon distance between speaker and listener). Telephone conversations may require lower levels unless amplifiers are used in ear pieces.

Noise control technology is well-developed and readily applicable to office environments. As with most control methods, retrofitting is usually more expensive and difficult than prevention in design stages. Noise control strategies used in offices involve either eliminating or controlling the source or interrupting the transmission path.

The best way to control equipment noise is to buy quieter equipment. The materials from which equipment is constructed as well as the amount of sound control engineering built in can significantly affect noise generation. Rubber pads or isolation damping devices can be installed under noisy equipment including typewriters to reduce vibrations and transmission to furniture and floors. Fan noise can sometimes be controlled by substituting fans of different design. Sound enclosures can be purchased or constructed for some equipment such as printers. Equipment noise can also be controlled by placement farther away from workers and even in separate rooms if possible.

Noise from ventilation systems can sometimes be reduced by installing baffles or diffusers of different designs, although care must be exercised to avoid degrading ventilation system performance.

Controlling noise in existing open plan offices can be highly problematic. In the design stage, attention to the height, sound transmission characteristics, and arrangement of work areas can result in better noise control. Door panels will soon be available as well. Another method which can be used is zoning the office into different areas depending upon equipment use, telephone use and conversation frequency, which reduces the exposure of at least some of the workers. Acoustical treatment of floors, walls, ceilings and windows can help but is fairly expensive and is usually not as effective unless the primary noise path is due to reflections from these surfaces.

In some cases, masking noise has been introduced to decrease the distracting effects of outside conversations and also provide privacy in conversation. Masking noise does, however, add to the overall noise level and could itself be a source of irritation.

Accidents and Injuries

As in any work environment, accidents can cause personal injuries in offices. Some of these injuries can be serious and appropriate safety measures must obviously be taken. Some of the most serious incidents have involved fires in high rise offices where inappropriate attention to exits and training drills, or inadequate alarm systems and fire control measures have contributed to unnecessary injuries and fatalities. The incidence of injuries among office workers is, however, very low in comparison to blue collar occupations.

Data related to injuries among office workers are difficult to obtain since most statistical analyses are categorized by industry type rather than occupation. In order to make some assessment of the nature and type of injuries suffered by office workers, the results of the 1982 Supplementary Data System for Occupational Injuries and Illnesses in Wisconsin were examined (Wisconsin, 1983). The data were compiled by the State of Wisconsin under contract with the Bureau of Labor Statistics. The results, tabulated by type of accident (Table 2-10), and nature of injury (Table 2-11), for the major white collar occupational classifications and selected clerical occupations are included.

Accident Types

Over-exertions and falls were the two most frequent types of accidents among white collar workers, accounting for just over half of all injuries. Among the selected office occupations, the distribution was somewhat different. Falls accounted for 46% of all injuries among this group. When these results are compared with those for all occupations combined, the most noticeable difference is the higher percentage of accidents attributable to falls among white collar workers (23% vs. 14%).

TABLE 2-10

Accidents Among White Collar Workers in Wisconsin by Type of Accident-1982

	Type of Accident							
Occupational Classification	Total Injuries	Over Exert.	Falls	Struck By	Bodily Reaction	Caught In	Motor Vehicle	Other
Prof/Tech	1351	390 (29)	264 (20)	256 (19)	160 (12)	23 (2)	49 (4)	209 (15)
Adm/Man	1183	377 (32)	271 (23)	200 (17)	96 (8)	46 (4)	54 (5)	139 (12)
Clerical	1636	509 (31)	423 (26)	279 (17)	137 (8)	61 (4)	30 (2)	197 (12)
Sales	699	194 (28)	172 (25)	107 (15)	56 (8)	13 (2)	63 (9)	94 (13)
All White Collar	4869	1470 (30)	1130 (23)	842 (17)	449 (9)	143 (3)	196 (4)	639 (13)
All Occupations	50860	15238 (30)	7072 (14)	10426 (20)	3272 (6)	2761 (5)	1115 (2)	10976 (22)
Selected Occupations								
Secretaries	82	16	52	13	6	1	2	1
Typists	38	8	16	5	2	3	1	3
Receptionists	14	3	6	1	2	—	1	3
Telephone Oper.	12	1	7	1	—	—	—	3
Bookkeepers	28	2	8	6	5	1	3	3
TOTAL (Percentage)	174	30 (18)	80 (46)	23 (13)	18 (10)	5 (3)	7 (4)	11 (6)

TABLE 2-11

Accidents Among White Collar Workers in Wisconsin
by Nature of Injury-1982

Occupational Classification	Total Injuries	Sprain Strain	Cuts Lacer.	Contusion Bruises	Fracture	Illness	Other
		Nature of Injury					
Prof/Tech	1351	594 (44)	82 (6)	74 (5)	156 (11)	124 (9)	321 (24)
Adm/Man	1183	428 (36)	86 (7)	67 (6)	173 (15)	54 (5)	375 (32)
Clerical	1636	718 (44)	111 (7)	174 (11)	165 (10)	114 (7)	354 (22)
Sales	699	290 (41)	42 (6)	52 (7)	84 (12)	30 (4)	201 (29)
All White Collar	4869	2030 (42)	321 (7)	367 (8)	578 (12)	322 (7)	1251 (26)
All Occupations	50860	20676 (41)	5215 (10)	4745 (9)	4243 (8)	3216 (6)	10476 (21)
Selected Occupations							
Secretaries	82	30	8	15	9	2	18
Typists	38	10	5	7	4	3	9
Receptionists	14	5	1	—	2	—	2
Telephone Oper.	12	4	—	3	2	1	2
Bookkeepers	28	4	—	6	5	5	8
Total (Percentage)	174	53 (30)	14 (8)	31 (18)	22 (13)	11 (6)	39 (22)

Nature of Injuries

Sprains and strains were the most frequent injuries (42%) among all white collar workers. Among the selected office occupations, the incidence of sprains and strains was somewhat lower (30%) and the incidence of contusions and bruises was higher. Illnesses accounted for 4-9% of the reported injuries, depending upon occupational classification. The nature of injuries suffered by white collar workers were generally representative of the entire working population.

Estimation of Injury Rates

The Wisconsin SDS data were also used to estimate injury rates in office occupations. The Wisconsin data include only cases involving fatalities, permanent disabilities, four or more calendar days of disability, and a few cases which do not meet these requirements. The data therefore underestimate the total number of injuries by some unknown amount; and the number of lost work day cases, possibly by a factor of 1.5-2. The SDS injury data were used in conjunction with 1980 census data. Since census data were used, any calculated frequency rates would not be comparable to typical injury rates based upon 100 man-years. The data can, however, be used to estimate the total number of injuries expected in the U.S. The distribution of employment by occupation within Wisconsin was compared with the U.S. distribution, in order to determine multiplying factors. Based upon these calculations, the data in Table 2-12 were generated. It is therefore estimated that approximately 9% of all injuries were suffered by white collar workers. Underlying this estimate is the assumption that Wisconsin injury experience is representative of the nation. The estimate is somewhat lower than previous estimates.

TABLE 2-12

Estimated U.S. White Collar Injuries

Occupational Classification	Reported Cases in Wisconsin	Ratio of Workers U.S/Wisconsin	Estimated U.S. Cases (1000)	Percent of Total
Blue Collar	39,049	47:1	1,835	74.0
Service	7,630	53:1	404	16.3
White Collar				
Adm/Man	1,070	50:1	53	
Prof/Tech	1,142	55:1	63	
Clerical	1,566	59:1	92	
Sales	621	36:1	22	
Farm	373	23:1	9	.4
Total	52,094		2,480	

As was pointed out in Chapter 1, only a portion of all white collar workers actually spend their time in traditional offices. Utilizing the estimates of office employment and the data from Table 2-12, adjusted injury frequencies were derived for white collar office employee. Since not all occupations within the white collar group experience the same injury rates, an attempt was made to adjust for this discrepancy as well. Two estimates are provided in Table 2-13. The first represents the number expected if all white collar occupations experienced similar rates and is considered to represent a maximum. The last column represents an adjusted estimate, determined by deleting injuries known to have occurred among occupations not considered to be office jobs. Both clerical and sales categories were found to contain a significant number of high injury occupations. As a result, the number of injuries estimated to occur among office workers is considerably reduced. The same was not true for administrative/managerial or professional/technical workers.

Based upon these estimates, approximately one of every 248 office workers suffered an injury. If these estimates are even close, it can be seen that the total number of injuries is quite small compared to other occupations, especially in consideration of the large number of office employees. As mentioned above, these figures certainly underestimate the total number of injuries by a large amount. In one of the few reports which included all injuries occurring in the offices studied, it was found that one of every 230 employees suffered a disabling injury while one out of 29 suffered an injury. The study involved the experience of one company (approximately 9000 employees) over a five year period (Baldwin, 1976). Based upon such information, the present estimates may represent only 12-13% of the total number of injuries suffered by office workers.

TABLE 2-13

Estimated U.S. Office Worker Injuries

Occupational Classification	Total Injuries (1000)	Total Adjusted for Percent of Office Workers (1000)	Total Adjusted by Including Only Office Occupations (1000)
	Estimates		
Prof/Tech	63	25	24
Adm/Man	53	45	45
Clerical	92	78	58
Sales	22	11	5
TOTALS	230	159	132

Causes of Accidents

A number of safety hazards in offices have been identified. Some of the most common include: office machines, furniture, and walking-working surfaces. The majority of all falls occur on walking surfaces (slippery surfaces or objects in the way), followed by falls on stairs and from chairs. Office machines and furniture are the most frequent causes of injuries classified as "struck by," "struck against" and "caught in." Over-exertion injuries can be caused by moving objects or materials.

Control of Safety Hazards

Control of most office office hazards could be accomplished by utilizing well-established hazard recognition and abatement techniques. These include such things as guarding of pinch points and sharp objects, good housekeeping, and training. Unfortunately, most offices do not employ safety specialists or if they do, the specialist must be shared with other "more hazardous" occupations. Numerous training aids on the subject of office safety are available, however. Many existing OSHA and state safety standards apply to offices, although few offices are ever inspected. The Business and Institutional Furniture Manufacturers' Association (BIFMA) has developed consensus standards regarding many safety aspects of office furniture. The safe design of office machines is currently left to individual manufacturers and is therefore controlled primarily by market forces, product liability suits being one of the most powerful forces.

Radiation

With each of the previously identified potential hazards discussed in this chapter, the conclusion has been reached that sufficient evidence exists to indicate that the hazard may actually exist within office environments and thereby result in an increased risk to the health and well-being of office workers.

The same conclusion cannot be reached in the consideration of radiation as a potential hazard in offices. This fact does not, however, warrant the exclusion of any discussion of radiation, especially in light of the widespread concerns of office workers and public interest groups related to possible radiation emissions from VDTs. Industry and government officials have stated unequivocally that there is no evidence to indicate that VDTs are unsafe. While some would take exception to this statement, it appears that most would find it difficult to refute. The major issue can, therefore, probably best be summarized as a concern about what we do not yet know, because of a lack of sufficient information. Some would also contend that there may be relevant information that we have not been made aware of. It is argued that we cannot wait 20 years to find out that long-term exposure to low level radiation similar to that emitted by VDT is indeed hazardous, and that steps must, therefore, be taken to provide an additional margin of safety, especially in light of the large number of individuals who will be using such equipment.

Overview

One of the central issues of general public concern over the safety of VDTs has been the question of whether the machines emit harmful radiation.

This concern was first raised in 1977 when two workers at a major U.S. newspaper developed cataracts and the possibility of their connection to VDT work was raised (Zaret, 1980). NIOSH performed a health hazard evaluation and, based upon measurements of radiation emissions at the worksite, concluded that there was no convincing evidence to indicate that the cataracts were related to the use of the VDTs. Despite continued assurances from various federal agencies (Moss, et al., 1977; Murray, et al., 1981; BRH, 1981; Environmental Health Directorate, 1983), industry (Wolbarsht, et al., 1980), and employers (Weiss and Petersen, 1979; Weiss, 1983; Petersen, 1983) there remains a persistent and growing concern over the potential effects of radiation emitted by VDTs. Much of this concern can be attributed to reported clusters of birth defects and spontaneous abortions among VDT operators (Slesin and Zybko, 1983). Other fears can be traced to periodic reports of preliminary research findings concerning biological effects of certain types of radiation; concurrent controversies concerning other radiation issues; occasional reports of unusual levels of low frequency VDT emissions; controversy over the accuracy or adequacy of measurement techniques and instruments; and mistrust of those with vested interests.

Radiation is a general term used to describe the emission or propagation of energy from a source in the form of waves or particles. Such emissions are given off at some level by most electrical products. Electromagnetic radiation is arranged according to frequency in a continuum referred to as the electromagnetic (EM) spectrum (Figure 2-2). Radiation with sufficient energy to cause a neutral atom or molecule to acquire a positive or negative charge (become an ion) is called ionizing radiation and includes the beta, gamma and x-ray regions of the spectrum. The nonionizing portion includes the ultraviolet (UV), visible, infared (IR), microwave (MW), radio frequencies (RF) and

FREQENCY IN HERTZ

10^{17} 10^{15} 10^{14} 10^{11} 10^{8} 10^{5} 10^{3}

<-IONIZING->|<——NON-IONIZING——>

GAMMA AND X-RAY	ULTRA-VIOLET (UV)	VISIBLE	INFRARED (IR)	MICRO-WAVE (MW)	RADIO FREQUENCY (RF)	VERY LOW FREQUENCY (VLF)	EXTREMELY LOW FREQUENCY (ELF)
Medical X-ray	welding, lamps, heaters, sun			TV, radio transmiss., sealers, telephone communications		communicat. equipment	power line appliances

EXAMPLE SOURCES

FIGURE 2-2. The electromagnetic spectrum - Frequency boundaries, energy sources and designations.

static fields. The lower RF frequencies are also further subdivided into very low frequency (VLF) and extremely low frequency (ELF) ranges. The regions are not sharply delineated and emissions tend to occur both at specific emitted frequencies and at high and lower harmonics.

Radiation Measurements

Radiation levels from VDTs have been measured in both the ionizing and nonionizing regions of the electromagnetic spectrum. Measurements in the ionizing region indicate that under typical operating conditions emissions are usually near .01-.02 milli Roentgen per hour (BRH, 1981; Cox, 1980) or 1/25th of the current BRH television standard (.5 mR/hr) and amount to about 1/10th the maximum permissible yearly exposure for the general population assuming full time VDT work (2000 hr/yr). Levels due to VDT emissions in some cases were found to be below the detection capability of the ionizing radiation measuring instruments (no measurable difference from background level). Emissions in the ionizing portion of the EM spectrum are not considered to be a problem by government officials and appear to be of lessor concern to those raising questions about various types of VDT radiation at the present time.

Measurements in the ultraviolet, visible and infrared regions as well as within the microwave frequencies have also been carried out and found to be well below what are considered hazardous levels according to official U.S. standards and recommended levels. Measurements of emissions in the nonionizing portion of the spectrum have indicated that most of the energy is concentrated in the lower portion of the RF range (below .3 MHz), where no U.S. emission standards have been established. Since the biological effects of nonionizing radiation have traditionally been thought to involve thermal effects, and because these lower frequencies were thought to pass through rather than be absorbed by human tissue (based on calculations made from theoretical models), the consensus in the past has been that there is little or no hazard potential. Consequently, there have been no national standards established for frequencies below 300 kHz (.3 MHz). This year the American Conference of Governmental Industrial Hygienists proposed a level of 614 V/M or 100 mW/cm^2 between 10 kHz and 3 MHz. The American National Standard Institute recently revised its standard to make it frequency dependent and lowered the maximum permissible exposure for certain portions of the spectrum from 10 to 1 milliwatt/cm^2.

NIOSH is currently evaluating research across the entire EM spectrum for a criteria document. They are continuing to work under the assumption that specific absorption rates (SARs) (which have been criticized as being primarily reflective of only thermal effects) can adequately account for potential health effects (Glasar, 1979). This same line of thinking has also been responsible for the lack of interest in biological effects and the lack of comprehensive research efforts concerning low frequency radiation. Recently NIOSH has begun preliminary epidemiological research on the mortality among operators of radio frequency sealers which emit radiation in this portion of the EM spectrum. Indications are, however, that the NIOSH criteria document currently being prepared will not be able to address the low frequency issue. The fact that occasional studies report effects will no doubt keep the issue alive.

More recently questions have been raised concerning extremely low frequency (ELF) radiation from VDTs (Byrd, 1982; Brodeur, 1983). Measurements of ELF radiation emissions (1-500 Hz) from VDTs have been reported to be similar to those emitted by TV's and a variety of household appliances (Environmental Health Directorate, 1983) although actual user exposures have yet to be determined.

Since proponents of safety standards and safeguards for VDTs generally admit that VDT radiation emissions are low, one of the central questions which continues to generate interest and concern involves the potential effects of long term exposure to low level radiation. Exposure limits have been established for emissions over much of the EM spectrum, on the basis of available evidence of biological effects. As stated earlier, there are no applicable standards for comparison throughout the RF, VLF, and ELF regions where VDTs also emit radiation. In fact, there is very little research data available to help confirm or deny the existence of potential hazards associated with some of the types of radiation emitted by VDTs and other sources. One of the comparisons that is made to dispel fears is that VDT emissions are similar to or lower than other sources of radiation in the environment. While some would argue this point especially in consideration of total exposures, VDT field directionality, and user proximity to the source, the one point of agreement must be that questions relating to the potential effects of exposures to low level and specific types of radiations are much broader than the question of VDT safety. They extend to fields emitted by other office equipment (lights, copiers, heaters, facility wiring, etc.) and consumer products, as well as broadcast communications and power transmission technologies.

Radiation and Fears of Adverse Health Effects

The major fears of adverse health effects due to VDT exposures stem primarily from the previously mentioned incidental observances of ocular effects (cataracts) and reproductive effects (spontaneous abortions, miscarriages, birth defects) among VDT operators. Cataracts of potential radiant energy origin among operators of office type VDTs (approximately 10 cases) have been reported by Zaret (1980). However, independent evaluations of some of this medical data by NIOSH and other physicians have concluded that there is no evidence to indicate that the cataracts were related to VDT use (Marshall, 1981). Measurements from VDTs used by these individuals have revealed that levels of radiation at the frequencies currently thought to cause such effects were far below the level conventionally considered necessary to produce cataracts. The results of surveys of Canadian workers (CLC, 1982) and newspaper workers (Frank, 1983) have revealed no increased reports of cataracts among VDT operators. A NIOSH study which included comprehensive ophthalmological examinations found no association between cataracts and VDT use, although it was pointed out that long term exposure effects could not be evaluated due to the limited exposure of the population studied (Smith, et al., 1982).

There have also been some reports of health effects from other radiation sources such as power lines (Lerner, 1980; Slesin, 1983). Such claims suggest nonionizing radiation, at least in part, rather than physical and mental demands alone may be a contributing cause of observed health effects such as eyestrain, fatigue, headaches, psychological disturbances, and chronic disease. These concerns are largely conjectural, however, and are considered premature due to the low levels of radiation emissions. Furthermore, as indicated in other sections of this report, the results of studies comparing VDT users and nonusers with respect to these types of complaints are equivocal. On the basis of available data, ergonomic problems and job demands appear to be more plausible etiological factors.

It is extraordinarily clear, however, that VDT operators in the U.S. and Canada (especially pregnant workers) are very concerned. The National Association of Working Women, which recently provided an 800 number that individuals could call to obtain information relative to VDTs, reported receiving

500-1000 calls per week during the first month (Gregory, 1983). The most frequently asked questions concerned vision, and the second most frequent were those related to possible reproductive effects. While there is no clear objective evidence to support such fears, they are nonetheless very real and widespread. In Canada, at least ten different employers have reportedly conceded the right of pregnant VDT operators to transfer to non-VDT work during pregnancy and a number of U.S. companies have reportedly made similar concessions. These actions by employers are affected to some degree by the lack of access to clear information on the subject, fears of liability claims, and some measure of prudence. Some employers have indicated that while they felt confident that no radiation risk existed, the stress related to such fears was indeed very real and was, in fact, the primary reason for allowing such transfers under currently existing contract provisions. This policy often serves to reinforce the fears of workers and their mistrust of studies. The Labour Canada Task Force on Micro-Electronics and Employment adopted a similarly conservative stand:

> "Any number of social and environmental factors ... might be the cause of the clusters of miscarriages and birth defects reported form some VDT worksites. However, until more conclusive epidemiological research studies completely rule out VDT(s) as a hazard to the fetus, the Task Force urges a precautionary approach. We recommend that a work standard be adopted that gives pregnant VDT operators the right to request and be granted reassignment to another position without loss of pay, seniority or benefits." (Labour Canada Task Force, 1982, p. 54).

The Canadian Labor Relations Board recently rejected the request of a pregnant VDT operator for alternative work, however (Microwave News, 1983).

The economic and psychosocial impacts on employers and workers which might arise out of the proliferation of pregnancy transfer policies can be well appreciated if one recalls the issues surrounding the promulgation of the lead standard.

It is also very clear that radiation measurement studies of VDTs will not solve this problem, nor will radiation monitoring of VDT workplaces.

Control Technologies

The question of control technologies and methods must address several issues including the nearly epidemic proportions of fear among pregnant VDT operators. Three basic alternatives are thus available: (1) conduct research which will assess the risk of VDT operators especially as related to reproductive effects, (2) reduce radiation emissions from VDTs, and (3) provide education and training for users. The first would appear to be the most important since the efficacy of reducing emissions depends upon whether a hazard exists and it is impossible to estimate how low emissions would have to be in order to alleviate concerns. Nevertheless, it is argued that where reductions in exposures are reasonably attainable, experience with other agents has proven the value of this approach, especially when uncertainties exist. The effect of the third is uncertain.

Research. It would appear that the most immediate need is for a large scale epidemiological study of VDT worker health. The Reproductive Hazards branch of NIOSH is currently conducting a feasibility study in an attempt to determine whether such a study should be conducted, and if so, how it would have to be done (Gordon, 1983).

Due to the complexity of studying radiation effects, laboratory research does not appear to offer a feasible approach to dealing with the issue of fear of radiation.

Standards. Standards for comparison of VDT emissions are available in the ionizing, ultraviolet, visible, infrared, microwave, and radio frequencies (down to 300 kHz). There are no such standards for any of the radio frequencies below 300 kHz including the very low and extremely low frequencies.

The standards of comparison often used in these ranges are the background level or other sources of exposure—the argument being that VDTs constitute a relatively small proportion of any potential risk which might exist. While this comparison may influence public policy decisions, it does not address the question of whether there is in fact a risk associated with these types of radiation, especially over long periods. Due to the scarcity of research data related to many types of radiation in the low frequency range, it is unlikely that safety standards will be established in the near future. It is also unlikely that the establishment of standards will do any more to alleviate concerns than do existing standards.

Testing of VDTs. FDA's Bureau of Radiation Health currently has statutory authority to require testing through performance standards for certain VDT product manufacturers (but not users) under the Radiation Control For Health and Safety Act of 1968 (Public Law 90-602) charging FDA with protection of the public from unnecessary exposure to ionizing and nonionizing radiation from electronic products. This authority also allows BRH to require corrective action by manufacturers. However, FDA-BRH has not promulgated specific performance standards for VDTs nor have they solicited emission data from VDT manufacturers. Some VDTs, that is those which can be used in TV applications, are currently subject to existing standards for TV receivers. These standards are limited to coverage of ionizing radiation. BRH has developed and published measurement protocols for all but the ELF and VLF portions of the EM spectrum (BRH, 1980).

Health researchers are interested in the radiation dose absorbed by an exposed individual. No nonionizing radiation dosimeters are yet available.

Currently, instrumentation capabilities allow only measurement of emissions from VDTs, that is the quantity of radiation given off by a terminal. Determining absorbed dosage from emission measurements is complex and inexact, involving mathematical considerations of factors such as body angles, directions, shapes and field distributions.

In view of the fact that certain cathode ray tube products (including oscilloscopes, TVs and VDTs) that have reached the market in the past have been found to emit significant levels of ionizing radiation (Weiss and Petersen, 1979; BRH, 1981), it appears obvious that regulations or performance standards such as those currently administered by FDA play an important role.

While field testing for radiation is the only way of determining the actual exposure of a worker, it is difficult and expensive. The value of such testing is questionable. Previous testing has, in all cases, indicated that, according to present safety standards, no hazard exists. Such field testing has also done little to quell widespread concerns.

Education. It is very clear that more and better education and training of both employers and employees concerning radiation is necessary. As pointed out above, efforts to date have been less than successful. It is, however, difficult to determine what the impact of training and education will actually be, especially because of the nature of the subject matter. The complications created by the necessary distinctions between emissions, exposures, doses and specific absorption rates; different regions of the electromagnetic spectrum and their respective units of measurement and biological effects; near-field vs. far-field; and instrumentation and methods of measurement, make the subject of radiation virtually incomprehensible to laypersons. The level of confusion which can be experienced by one attempting to evaluate VDT-related radiation studies is examplified in Table 2-14 which indicates the variety of units of measurement utilized and the location at which measurements have been recorded. Evaluation of the risks associated with radiation exposure must be carried out by experts. The success of any education or training efforts will, therefore, depend, to a large extent, upon the credibility of such experts and the degree of concensus between them.

Other Control Methods. Other techniques are available which could potentially reduce radiation emissions including increased shielding and different display technologies such as thin film electroluminescent.

Some public interest groups and labor organizations have advocated such control methods based primarily on the belief that even very low radiation emissions will eventually prove to be hazardous and added precautions are therefore justified. The counter argument by industry has been that VDTs already emit less radiation than numerous other devices in both work and non-work environments, and therefore any further reduction would have little if any impact on total exposure.

TABLE 2-14

Units and Locations of Radiation Measurement Reported in VDT Studies

Electromagnetic Field	Units	Location at Which Measurements Were Recorded
Ionizing	mR/h micro R/h	
Ultraviolet	W/m^2 W/cm^2 W/cm^2 sr micro W/cm^2	
Visible	fL W/m^2 W/cm^2	- 5 cm from screen - at operator position
Infrared	W/m^2 W/cm^2	- 30 cm from screen - screen surface
Microwave	V/m V^2/m^2 W/m^2 mW/cm^2	- position of maximum reading - at back yoke
Radio Frequency		- 10 cm from side
Electric	V/m V^2/m^2 mW/cm^2 W/m^2	- top - back
Magnetic	A/m A^2/m^2 m W/cm^2	
Extremely Low	A/m	

CHAPTER 3

RELATED TOPICS

Concerns and Activities of Interest Groups

The following section provides a brief summary of typical interests and activities of different organizations which have particular interests or roles in the issue of office health and safety. It appears safe to conclude that a central concern of all or most of these groups is the video display terminal issue. Four categories of interest groups will be considered: (1) employees, (2) employers, (3) manufacturers, and (4) government. In addition, foreign activities will be discussed. Some of the activities described below as representative of one group may overlap with others.

Employee Interests

One of the most active, vocal, and visible groups currently involved in office worker safety and health issues has been 9 to 5, National Association of Working Women. This non-profit organization currently has 17 local affiliates around the country and 12,000 members. The organization is also affiliated with the Service Employees International Union, District 925 which has a membership of 4,000. While a major concern of Working Women has been upgrading clerical jobs and fighting sex discrimination policies and practices, the organization has been actively involved in issues related to safety and health in the office. These activities have included organization and participation in conferences and workshops on office health issues, publication of numerous materials, and surveys of office workers. The basic philosophy of the group is to alert, educate and organize office workers to improve working conditions.

A number of labor unions have been involved in office work issues to varying degrees. In 1979 only 6.5% of those classified as clerical workers were organized. More than 40% of the unionized workers were in the public sector, and only 1.5% of the insurance industry was unionized. Although many more unions have been directing their organizing efforts toward white collar workers, they still do not represent a large percentage of the membership of most unions. Only 9 unions have more than 50% of their membership in clerical occupations. Approximately 25% of all professional and technical employees belong to unions or associations (Kilgour, 1983). Some of the major unions which include significant numbers of office workers are:

- American Federation of Government Employees (AFGE)
- American Federation of State, County and Municipal Employees (AFSCME)
- Communications Workers of America (CWA)
- Brotherhood of Railway and Airline Clerks (BRAC)
- International Brotherhood of Electrical Workers (IBEW)
- International Brotherhood of Teamsters (IBT)
- Insurance Workers International Union (IWIU)
- International Association of Machinist and Aerospace Workers (IAMAW)
- Office and Professional Employees International Union (OPEIU)
- Service Employees International Union (SEIU)
- Telecommunications International Union (TIU)
- The Newspaper Guild (TNG)
- United Steelworkers of America (USWA)
- United Auto Workers (UAW)
- United Food and Commercial Workers (UFCW)

Activities have typically included the following:

- Development of manuals on safety and health for office workers,

- Development of manuals on VDT related problems,
- Training programs for members (VDTs, health problems, stress, ergonomics),
- Participation by staff in office health, stress and VDT workshops and seminars,
- Support of state legislation related to VDTs,
- Sponsorship and participation in research,
- Development of proposals for collective bargaining.

Most unions include some type of language in their contracts concerning safety and health, and a few have specific language dealing with office technology and VDTs.

Employers

While numerous employers have been devoting more effort to dealing with safety and health hazards for office workers (usually related to VDTs), there has been very little activity by employer organizations. The threat of legislation in various states will undoubtedly change this situation. For example, the Associated Industries of Massachusetts recently held a meeting for New England area industry associations to develop strategies concerning legislation.

A number of consensus standards committees are currently active in areas related to office safety and health. While these are not exclusively employer organizations, they do tend to be dominated by management.

Manufacturers

The most prominent manufacturers association is the Computer and Business Equipment Manufacturers Association (CBEMA). This organization represents manufacturers of computers, data processing, office equipment and supplies. The organization has about 40 members representing approximately 85% of the industry. One of the organization's current interests involves the issue of VDT safety. CBEMA activities include: the establishment of committees on environment, health and safety, and human factors; participation in legislative hearings; participation in standards setting groups; and publication of informational materials. A similar organization including many of the same members operates in Europe (European Computer Manufacturers Association [ECMA]).

Other manufacturers' organizations with a potential interest in office health and safety issues include the Business and Institutional Furniture Manufacturers Association (BIFMA) and the National Office Products Association (NOPA). Each organization represents substantial portions of the furniture and office products industries.

BIFMA activities have been concentrated primarily on the development of concensus performance standards for office equipment. A total of six standards and test procedures have been developed to date addressing such things as durability, stability, strength, flammability and safety of chairs, desks and file cabinets. One of BIFMA's primary function is serving as an information resource for its members and outside market demands. Standing committees include:

1. Engineering Standards Committee
2. Information Systems Committee
3. Communication and Industry Liaison Committee
4. Education Committee
5. Governmental Affairs Committee

BIFMA has over 100 members representing 90% of the industry's sales volume.

NOPA has funded a major study concerning trends in office environments. While a principle objective of the initial research was forecasting industry trends, preliminary reports have placed a heavy emphasis on the importance of office design and office equipment in determining worker comfort, health and productivity.

The Chemical Manufacturer's Association (CMA) has supported a proposed OSHA "Hazards Communication Standard" which excludes most office workers.

Government

The National Institute for Occupational Safety and Health bears the primary responsibility for conducting research and developing information concerning office health and safety. Relevant activities to date have included research, literature reviews, publications, seminars, training programs and health hazard evaluations. Some of the recent NIOSH activities are described below:

- Contract with a university to investigate effects of VDTs.
- Contract with a university to investigate visual effects of VDTs.
- Development of a training program and manual on VDT health problems.
- Literature reviews on stress factors in office and clerical work and VDT problems.
- Health hazard evaluations related to stress, air quality and VDT problems (radiation, ergonomics, stress, health).
- Internal research related to stress, VDTs, ergonomics.
- Sponsorship of several conferences on clerical/secretarial health issues.
- Development of a criterion document on radiation.
- Sponsorship of a National Academy of Science study of visual effects of VDT work.

Occupational Safety and Health Administration (OSHA). OSHA has not been actively involved (at least at the national level) in any of the issues relating to office hazards. A recently promulgated "Hazard Communication Standard" only covers those working in manufacturing industries.

Bureau of Radiological Health (BRH). BRH activities have included investigation of radiation emissions from VDTs in laboratory and field settings, as well as intramural and extramural research on radiation.

Environmental Protection Agency (EPA). EPA sponsored a major study of indoor air quality which included information concerning air quality in buildings. Few specific studies of offices have been conducted. EPA is working on a general population standard for exposure to nonionizing radiation.

State Government. Activities at the state level include VDT bills which have been introduced in seven different states. In two of these states, the issue has resulted in the establishment of committee or technical studies. No legislation has been passed. As of the Fall of 1983, thirteen states had passed "hazard communication standards" or "right to know" legislation. It is uncertain whether the recently published federal standard can preempt these stricter state standards.

International Activities

Activities related to office hazards in foreign countries have generally been concerned with new technologies and usually limited to VDT issues. Some of the earliest activities were studies conducted by the Technical University of Berlin for the German Government and an Austrian Trade Union Council study on video display terminals. Australia promulgated a general ergonomics standard which applies to offices in 1975. In France, a seminar on visual problems related to VDTs resulted in a 1977 report and the formation of a study groups. In 1978, the results of the Technical University of Berlin study were published and eventually formed the basis for the widely distributed VDT Manual (Cakir, et al., 1980). The recommendations also formed the basis for the German DIN standard which will take effect in 1985, specifying certain image quality and equipment adjustment requirements. In 1978, the Swedish Board of Occupational Safety and Health (SYNBOSH) issued a national directive concerning the reading of visual display screens. About the same time, the Defense and Civil Institute of Environmental Medicine prepared specifications to aid the Canadian Federal Government in selecting VDTs for federal employees. In 1980, a report describing the results of a study conducted by the New Zealand Department of health were released.

The Norwegian Labor Inspectorate's Directorate for Work Councils issued regulations and guidelines for VDT use under the Work Environment Act. Two reports were issued almost simultaneously in 1982 by the Canadian Labour Congress (CLC) and a task force of the Canadian Government. The CLC study includ [illegible] the results of a survey and both reports included recommendations for V[illegible] The Canadian Government Task Force report was the first case in which a government-related group suggested pregnancy leaves for VDT operators. Provincial governments in both Ontario and British Columbia have considered VDT legislation. The Australian Council of Trade Unions adopted a comprehensive safety and health policy on screen based equipment in 1982 and is currently attempting to negotiate agreements with major employers.

In 1983, the International Standards Organization met to consider the development of an Ergonomic Standard for VDTs. Proposals were submitted by Norway, Great Britain and France but no action was taken. Working groups were established and the next meeting is scheduled for late in 1984. Due to the normal time delays in developing standards, no ISO standards could be expected until at least 1986.

Standards Activities Related to Office Hazards

Standards, regulations and guidelines directed at controlling office safety and health hazards have been most apparent in Europe. Germany, Norway and Sweden all have adopted various types of standards, rules or guidelines relating to VDTs. Similar activities are underway in Great Britain.

At least two Canadian Provinces have considered legislation and the national government has expressed an intention to further consider the need for legislative control. As of this time, none have been adopted.

In the United States, such legislative efforts have been limited to the state level. The only federal government involvement to date has been a set of guidelines prepared by NIOSH and first published in 1980. At least seven states have considered VDT legislation and the activities of a variety of public interest groups suggest that similar legislation will be introduced in a number of other states.

Most of the proposed state standards have been modeled after European regulations and have generally dealt with ergonomic factors, VDT design, rest breaks, restriction on maximum use, visual exams, and pregnancy transfers. These activities are summarized in Table 3-1. As of this date, no legislation has been passed regulating VDT use, although two states (Connecticut and Maine) have passed bills requiring studies of related issues.

An American National Standards Committee (ANSI) was recently formed to prepare voluntary consensus standards dealing with ergonomics. Other standards activities in the U.S. which may have a potential impact on office

TABLE 3-1
Proposed Legislation Addressing Office Equipment Health and Safety

	Requirements							
Governing unit	Vision exams	Pregnancy transfer	Adjustable equipment	Rest minutes per hour	Hour limit per day	Hazard communication	Current status	Other stipulations
Connecticut			*	20/2 hr		*	Technical Study	glare guards, character size, heat exhaust, radiation monitoring and research
Illinois	*		*	15/2 hr		*	Tabled	
Maine	*			15/2 hr		*	Study	semiannual VDT maintenance, state agency work rules authorized
Massachusetts	*	*	*	15	5		Proposed Study	copystands, work redesign, surveillance notification, stress red
New York	*	*	*	*	*		Bill Introduced	radiation protection jackets dropped
Oregon	*	*	*	30/2 hr		*	In Committee	glare guards, local light, env. light, VDT maintain, no work end of shift-30
Ohio	*	*	*	*	*		Bill Introduced	glare reduction, metal shielding, restrictions on performance measurement
Washington	*	*	*	*		*	Rule Making	

hazards include state and federal legislation concerning the labeling of hazardous materials and providing information to users ("right to know legislation") and some activities related to radiation. An ANSI standards committee has been attempting to revise the old occupational exposure standard to make it frequency dependent and more stringent for certain portions of the spectrum (30-300 Mhz) and less stringent in the higher (1500 Mhz-100 Ghz) and lower frequencies (300-Khz-3 Mhz). NIOSH is currently preparing a criteria document on radiation.

A number of states and cities have passed general population standards for radiation exposure.

Virtually all states have local standards and codes relating to buildings (e.g. ventilation, lighting, temperature), although most are merely design standards.

Relationship Between Office and Non-office Hazards

Consideration of the potential adverse effects of office hazards described, as well as control technologies and policy strategies should be viewed in relation to their potential impact on other non-office exposures. Much of the discussion has concentrated on clerical workers, who represent the largest percentage of office workers, since they would appear in most cases to experience the highest risks. There are a number of unique characteristics of this group of workers which differentiate them from other work groups:

- the majority are women
- most receive low pay
- opportunities for advancement are minimal
- few belong to labor unions

These characteristics could affect the widespread applicability of policies and strategies developed to control office hazards. Nevertheless, there are some obvious implications which deserve consideration.

- The general question concerning the potential long term effects of low level exposures to radiation and air pollution has an impact on virtually all members of the work force.
- The effects of microelectronics technology and automation have already had a substantial impact on large groups of workers within all sectors of the non-agricultural work force. Issues such as job displacement, machine control and monotonous work have already surfaced in a variety of non-office occupations. Video display terminals will become more common throughout all workplaces, as well as homes and schools. Although there uses may differ, equipment design problems, intensive visual demands, and other ergonomic features will be factors which may be common to all.
- Stress appears to be one of the most inherent commonalities between different occupations. While different factors may contribute to stress in different jobs, control strategies developed within the office setting (e.g. job redesign, worker participation, job control) would undoubtedly prove to have widespread implication for non-office workplaces.
- Ergonomic approaches to hazard control have had relatively little impact within other sectors of the work force. The recent attention given to designing office equipment based upon ergonomic principles could accelerate the trend toward designing work to fit the worker.

CHAPTER 4

STRATEGIES FOR CONTROLLING HAZARDS

In order to reduce hazards, two considerations are essential. The first involves the recognition and identification of hazards and the development of specific control technologies which serve to abate these hazards. The second consideration involves developing public policies or strategies which assure that hazard control actually is carried out. The variety of hazards which potentially exist in office environments have been described in previous sections. For each hazard, an attempt was made to analyze the level of risk based upon typical exposures and number of individuals exposed. In addition, different control technologies which might serve to abate these recognized or potential hazards were presented and evaluated in terms of their effectiveness and costs for each of the hazards. Table 4-1 serves to summarize briefly the analysis of potential hazards, sources, and potential control strategies which have been described. The control technologies fall into the following categories.

1. Engineering Controls. Through the use of engineering controls, the sources of hazards are physically reduced or eliminated. This may be accomplished by redesigning equipment (better design of equipment such as VDTs, ergonomic design of office furniture, providing adequate ventilation, enclosing air contaminant or noise sources, controlling illumination); or removing or substituting less hazardous materials, equipment, etc. (e.g. chemicals in office products, selection of better designed furniture or VDTs).

TABLE 4-1

Hazard Control in Offices

	Potential Health Effects*	Potential Hazards	Hazard Control
Air quality	Irritation, discomfort, outbreaks of disease, sensitization	Formaldehyde, ozone, organics, allergens, micro-organisms	ventilation, substitution enclosure, filtering
Temperature	Discomfort	Heat, cold, humidity, air circulation	radiant control, air circulation, different location, individual control, humidity control
Musculoskeletal Stress	Neck, shoulders, back, arms fatigue and chronic disorders	Workstation design, chair design, task repetitiveness, constrained posture	Furniture ergonomics, task redesign, job enlargement, rotation, rest breaks, exercise
Visual Stress	Eyestrain, burning or itching	Lighting, close work, quality of VDT and other viewed material, dry air, stress	Vision exams, illumination controls, equipment design, rest, exercise, work layout
Psychologial Stress	Anxiety, tension, stress, boredom, headaches, job dissatisfaction, alienation, absenteeism, turnover, behavioral problems (smoking, drinking), ulcers, CHD, diabetes and other diseases	Repetitiveness, monotony, monitoring, lack of promotional opportunity, lack of job security, lack of control, pacing, piecework, work environment	Stress management, wellness, exercise, job redesign, worker control, job enlargement, job enrichment, rotation, environmental control
Noise	Irritation, interference, distraction	Conversations, equipment, ventilation systems	Barriers, equipment design, enclosures, absorption
Accidents	Traumatic injuries	Work surfaces, furniture, equipment, lifting	Guarding, hazard removal, training

*Almost all potential hazards may affect health indirectly by causing emotional stress, especially air quality, temperature and noise.

TABLE 4-1
(Continued)

	Potential Health Effects*	Potential Hazards	Hazard Control
Radiation	None yet established	Low level radiation	Shielding, low voltage, alternative designs, work removal, time limits

*Almost all potential hazards may affect health indirectly by causing emotional stress, especially air quality, temperature and noise.

2. Administrative Controls. Hazards may also be controlled by implementing certain changes in administrative procedures. Examples include removing individuals from sources of hazards, rotation to less hazardous or less stressful duties or work areas, smoking restrictions, medical surveillance, work-rest schedules, and job enrichment.

3. Behavioral Methods (Personal Control). In situations where the feasibility of controlling certain hazards is questionable (especially in cases where individual differences play a major role or when exposure is brief), certain behavioral approaches may be useful. These include training (e.g. handling of materials, adjustment of equipment, adjustment of lighting, operating procedures, type of clothes to wear), exercise to relieve discomfort, and stress management techniques.

The identification of hazards and hazard control techniques obviously does not assure abatement. The second step involves informing employees, employers, and manufacturers. The third step involves providing sufficient motivation to assure that hazard abatement is actually carried out. All three steps require the development of public policies or strategies for implementation. The remainder of this chapter provides a discussion of alternate strategies as they relate to the control of office hazards.

The moral, legal and economic issues surrounding the development of public policies have been addressed in relation to a variety of work related hazards in the past. The same arguments obviously apply to the control of hazards in offices. Two of these arguments are especially pertinent to the consideration of office hazards and relevant control strategies. First of all, public debate on occupational safety and health issues seldom has successfully gone beyond the issue of demonstratably physical impairment. In view of the nature of most of the office hazards considered, the clear demonstration of physical impairment is often difficult. At the same time, it is clearly evident that the concerns of office workers encompass a much broader definition of impaired health which includes at least freedom from psychological distress and pain. The need for a broad definition of occupational health and safety has been debated on both philosophical and scientific grounds.

The objectives of occupational health, as defined by the International Labour Organization and the World Health Organization (1963), include "... the promotion and maintenance of the highest degree of physical, mental, and social well-being of workers in all occupations; ..." The philosophy behind the American Conference of Governmental Industrial Hygienists' threshold limit values is as follows:

> "The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, or other forms of stress may form the basis for others." (ACGIH, 1983).

Even if irritation, pain, and distress are not considered as manifestations of impaired health, it can be argued that they are often significant precursors of impending impaired health. For example, psychological distress may lead to ulcers or coronary heart disease.

The second problem concerns the specific issue of establishing permissible exposures. Whereas initial decisions are generally made based upon scientific knowledge, compromise has usually been sought (with few exceptions) at some level which reduces exposure to a level of "acceptable" or "reasonable" risk based not only upon scientific knowledge but also upon economic and technological considerations. As a result, permissible exposure levels (especially when legislated) generally do not provide safety margins for protection against potential unknown long-term effects, synergistic effects, aggravation of pre-existing conditions, or hypersensitivity.

It is evident that any policy which is developed without giving adequate attention to these issues will fall short of a satisfactory outcome in the eyes of concerned office workers.

Alternate Strategies For Implementing Office Hazard Controls

There are four approaches generally employed, individually or in combination, in efforts to reduce safety and health hazards: (1) regulatory activities; (2) information generation, dissemination, and utilization; (3) market incentives; and (4) manpower development. The particular mix of strategies employed in comprehensive public policy approaches to the reduction of technological hazards in the U.S. have most often stressed the first approach.

Regulatory Activities

Regulatory control of hazards includes the legislation and administrative rules developed to establish limits, standards, guidelines, product specifications, compliance methods, enforcement procedures and penalties in order to attain safer exposure levels, insure healthful work practices, prohibit unsafe products, or otherwise protect those persons potentially at risk. Regulations providing certain rights to workers and their representatives have also been included in recent U.S. legislation, and some European countries have extended the rights of workers to include local control over hazards.

Advantages and Disadvantages of Regulations. The basic argument used by employee groups and organizations in support of regulations is that nothing will be done unless employers are forced into action. Standards provide employees with an essential tool which can be used to force employer action to reduce hazards. While the collective bargaining process provides an alternative, only 25% of all workers are organized and only 8% of the white collar work force is organized. Collective bargaining is, therefore, not a reasonable alternative in this case. While employers and manufacturers naturally oppose regulation, there are situations in which they do provide certain advantages. That is, compliance with a standard may reduce liability or protect the employer or manufacturers. For example, VDT manufacturers and employers have pointed out that radiation emissions are well below existing standards. In other cases, employers may be unsure of what to do. A standard may thus provide specific and definable goals.

The most often cited disadvantages of regulations include:

- Manufacturers and employers may be satisfied with only meeting the requirements of the law, thereby preventing or reducing the possibilities of reducing exposure below prescribed levels.
- Regulations interfere with workplace relations, polarizing attitudes.
- Regulations restrict the use and benefits of new technology.
- Regulations may require certain activities in spite of the lack of any evidence of adverse health effects, thereby imposing unnecessary economic burdens.
- Regulation may adversely affect productivity.
- Regulations tend to stagnate and not adapt to new hazards and control technologies.

Determining Safe Exposures. The establishment of specific exposure limits or design requirements demands that sufficient information be available concerning the causal relationship between exposure and health effects. Even in those cases where direct relationships are established (e.g. noise, lead, asbestos), the establishment of a particular level usually represents a compromise based upon limited knowledge and economic and technological feasible. Virtually all of the hazards described in this report face this difficulty. Ergonomic and stress related problems do not easily lend themselves to the application of specific standards because of the lack of unequivocal information relating specific exposures to adverse health effects. The lack of adequate information concerning the long term effects of the low level exposures characteristic of radiation, air contaminants, and noise present similar problems.

Product vs. User Standards. Product standards may be imposed by requiring that manufacturers meet certain standards or that adequate information be provided concerning the hazards associated with use of the product. One of the principle advantages of product standards is the relative ease of enforcement compared to standards imposed on users or employers. For example, one can contrast the feasibility of imposing a design requirement on approximately 150 VDT manufacturers versus field testing in excess of 10 million terminals. When recognized hazards and control methods are available, inclusion of hazard control technology during production is less expensive than retrofitting. At the same time an unnecessary cost may be imposed if a hazard does not exist in the workplace because of the nature of use. Product standards also fail to control products already in use. While warnings and labeling do not assure the safe use of products, they do provide concerned users with valuable information which can be helpful in selecting control strategies. Product standards would also be applicable to only some of the potential hazards which might exist in offices.

Design vs. Performance Standards. Design standards specify exactly what and how control of a hazard must be accomplished. A performance standard only establishes what must be accomplished. Performance standards may occur in two forms. The most common is represented by a threshold limit value (e.g. noise and air contaminants). Less common are standards which simply require that recognized hazards be eliminated (e.g. "general duty clause" section 5(a)(1) of the Occupational Safety and Health Act, 1970).

Performance standards are usually favored by manufacturers and employers since they allow freedom in selecting the most efficient method of meeting the requirements of the standard. In some cases, design standards are easier to accomplish, however, especially where they eliminate the necessity for expensive testing. Unions have usually supported design standards for the same reason (i.e. it is much easier for workers to determine whether specific design requirements have been met than to measure exposure levels). Design standards are, for the same reasons, easier to enforce by regulatory agencies.

A major disadvantage of design standards is that they may not guarantee a safe level of exposure. For example, as was indicated in Chapter 2, ventilation requirements for buildings are usually based upon design standards. In many cases, once in operation the systems are found to perform at levels far below design expectations. Design standards also impose restrictions where no hazard exists. For example, required glare shields and detachable keyboards for VDTs may be unnecessary in some environments or with certain limited uses.

Engineering vs. Administrative Controls. Engineering controls are generally preferred because they reduce or eliminate the source of exposure. In other cases, there may not be any feasible engineering controls and administrative procedures such as rotation, rest breaks and removal from the source of exposure may be necessary. Administrative controls may lead to discriminatory practices due to age, sex, handicaps or hypersusceptibility. Administrative controls are often complicated by collective bargaining agreements which specify job values, rest breaks and job duties.

State vs. Federal Regulation. All interested parties have generally been in agreement (although for different reasons) in favoring federal regulation over state regulation. Notable exceptions have, however, occurred recently concerning hazard communication ("right to know") legislation and proposed VDT legislation. In the first case, labor and public interest groups have supported stricter state standards and, in the second case, have supported state standards because of the lack of any anticipated activity at the federal level.

Feasibility and Effectiveness of Regulation. Several obstacles can be identified which would cast doubt on the effectiveness of regulatory activities to control office hazards.

(1) Federal and state compliance activities are already grossly overburdened. Before recent cutbacks in budgets and staffs, it was already projected that each business might expect to be visited only once in several years. Many local jurisdictions have chosen to target certain high hazard industries. It is questionable, therefore, whether limited inspection forces could or would be redirected toward offices where very limited evidence of serious risks in comparison to construction and manufacturing industries exist. While complaint avenues would be opened up, even these procedures have been seriously restricted by personnel limitations and policy directives.

(2) The effectiveness of regulatory activities are also questionable in view of the record for standard setting procedures as is witnessed by the limited number of revisions and new standards promulgated in recent years. Standard setting procedures in the United States have not established a precedent for the development of over-protective or prudent regulations that would be required for virtually all of the office hazards described.

(3) Many of the hazards encountered in offices do not easily lend themselves to control through standards. Most notable are ergonomic and stress related problems. Both are highly dependent upon local environmental conditions, the nature of the job, and management styles.

Standard Setting Activities. While standard setting activities have been pursued in a number of foreign countries, activity in the U.S. has been limited to the state level. These activities have been summarized in Chapter 3 of this report. Proposed state legislation has been criticized by computer and business equipment manufacturers because it addresses only VDT work. This is generally true and is an important consideration in evaluating the potential effectiveness of any state regulatory activity in controlling office hazards.

Table 4-2 includes a brief overview of some hazard specific considerations related to regulatory activities.

Generation, Dissemination and Utilization of Knowledge

Information is the crucial currency involved in the solution of all occupational health and safety problems. Generation of knowledge refers to research activities which provide the data base concerning the nature of

TABLE 4-2

Considerations Related to Regulation of Office Hazards

Potential Hazards	Considerations
Air Quality	Lack of data available on long term low level effects prevents development of standards. In order to provide a level of protection adequate to prevent irritation, discomfort, sensitization, and protection for hypersensitive individuals, threshold levels would have to be much lower than currently established levels. Ventilation performance standards would prevent many current problems and provide better protection than current design standards. Measurement of performance would be difficult for most offices without outside assistance.
Temperature/Humidity	Current performance standards exist in most local building codes, however, they do not address zone temperatures (thermostat setting is the only consideration). While it is clear that closer regulation of standard temperatures, humidities and ventilation rates would improve temperature comfort for a substantial number of individuals, it is unclear how many individuals would still experience problems due to varying comfort ranges.
Musculoskeletal problems	The lack of clear data indicating the relationships between specific design factors and musculoskeletal problems makes legislation difficult. Requirements for adjustable workstations (chairs, tables, layout) would help a substantial number of people. However, many improvements can be made without extensive user adjustability built into furniture, and at a lesser cost. While performance standards would therefore, be more desirable, they would also be much more difficult to enforce since the worker would have to prove that the equipment was responsible for problems. Likewise, job design factors (rest schedules, task variation, etc.) are not easily amenable to design standards due to variations in job demands.

TABLE 4-2
(Continued)

Vision problems	While certain design standards related to image quality and illumination are potentially realistic, more data relating effects to causes is necessary. Design standards for visual demands could be established for certain highly demanding or repetitive tasks based upon currently available data. Defining the lower limit of "high visual demands" would, however, be difficult as would evaluation of specific jobs. "Vision conservation" programs including periodic eye exams could be developed, although specifying the exposure level at which evaluation would be required would be difficult.
Stress	Stress, due to the broad scope of stress and the difficulty of measurement, does not easily lend itself to traditional forms of hazard control legislation. Several European countries have developed worker involvement and job enrichment types of legislation.
Accidents	A number of current state and federal standards apply to offices. Examples include electrical, fire protection, and building codes; and standards for working surfaces and machine guarding. Due to the relatively low rate of accidents in offices, inspections are rare, however.
Noise	While maximum noise exposure levels could be established for office work, it would be difficult to define and measure irritating and distracting noise, in other than the broadest terms.
Radiation	Current standards exist for much of the electromagnetic spectrum. There are no standards for certain frequencies in the non-ionizing region, and there is very little data concerning risk in this region, making standards setting difficult. Long term effects of low levels are not well established. Field enforcement would be very difficult, and product performance standards would appear to be the only feasible control available, should the need for standards be established.

hazards, control strategies and technologies. Dissemination of knowledge or information access is provided by publication of technical information in useful forms and in a timely fashion. Utilization of knowledge includes demonstration projects, educational programs, and training activities that apply available information to the development of human skills and abilities.

Many of the most basic questions about occupational health and safety hazards remain unanswered. These shortcomings are not surprising in light of historical failures to recognize occupational contributions to health, and the rapid pace of technological implementation in the workplace. The result is a tremendous backlog of research work that has only recently been acknowledged. The long period of neglect in health and safety areas means that current knowledge about hazards is unsophisticated and imprecise relative to information available about the technical and economic advantages of specific production processes and different operational procedures. This research uncertainty places health and safety arguments about suspected hazards from products and processes, potential health effects and estimated social and personal costs at a substantial disadvantage relative to the more adequately documented and better substantiated arguments of business and industry that can be assembled to attest to the utility and desirability of products and processes. Uncertainty increases controversy and decreases both the likelihood of controls and the effectiveness of controls. Table 4-3 summarizes some of the problems associated with information generation, dissemination and utilization for the different potential hazards in office work.

This approach to hazard control assumes that once information has been made available to responsible parties (manufacturers, employers, workers) that sufficient motivation will be present to assure that appropriate steps will be taken to abate hazards. Historically, labor unions, public interest groups and government have concluded that it is necessary to include some level of

TABLE 4-3

Considerations Related to Generation, Dissemination and Utilization of Information Relevant to Specific Office Hazards

Potential Hazard	Considerations
Air Quality	There is currently no good information available concerning the number of people at risk. There also is a lack of information on long term low level exposures. Utilization of available information concerning ventilation is also inadequate. The information that is available has not been adequately disseminated. As a result, available control strategies are not used. Part of this is due to the lack of qualified personnel in critical positions.
Temperature/Humidity	Information is readily available but does not reach those who make decisions in offices. Temperature and ventilation requirements are generally established in a piecemeal fashion by designers, architects, heating and ventilating engineers and temperature control engineers according to design specifications. Performance evaluations are not routinely performed. The major problem, therefore, lies in utilization of information.
Musculoskeletal	Information dissemination has probably exceeded information generation in this area. Most of the information has been based upon basic principles and "expert" opinions. Consequently, some recommendations have been made without adequate supporting data. In certain areas (e.g. chairs), it would appear that many are readily willing to utilize available information. More accurate and reliable information is definitely needed.
Vision	Data concerning the relationship between specific problems and potential causes is lacking. While a variety of potential causes have been identified, the relative importance of each and the efficacy of various control strategies is unclear. Much of this information is being disseminated, although not systematically, specifically to those who play a role in design. The variety of information and availability of alternative control strategies makes it difficult for end users to make proper decisions.

TABLE 4-3
(Continued)

Potential Hazard	Considerations
Stress	The biggest problem in relation to stress is the lack of willingness to utilize available information even when proven control strategies appear evident. Many of these control strategies involve considerable departures from traditional management approaches. The lack of quantifiable measures of stress outcomes presents a serious impediment. The relationship between stress-related health outcomes and potential economic incentives such as absenteeism, turnover, and productivity has not been adequately disseminated.
Noise	Control strategies are available but are often expensive. The lack of clear evidence relating irritating and distracting noise to health, well-being and productivity combined with the costs of controls provide little incentive to eliminate such noise.
Accidents	Information concerning office accidents is readily available in publications and films from a variety of organizations.
Radiation	The major problem lies in generation of information concerning risks associated with low level exposures and specifically within certain frequency ranges of the non-ionizing portion of the electromagnetic spectrum. There is also a lack of data concerning the question of adverse outcomes of pregnancy among VDT operators.

regulatory activity in the process. It is readily apparent from the discussion in previous sections that the generation of information with respect to certain hazards has been grossly inadequate, especially as it relates to the determination of risk. Some of these shortcomings include:

- typical and extreme exposure levels in office environments have not been established,
- effects of long term low-level exposure are unknown,
- number of workers exposed to specific hazards is unknown,
- inadequate demonstration of the effectiveness of proposed control technologies,
- inability to quantify the health, social and economic costs of stress, discomfort and job dissatisfaction.

In the face of uncertainty, techniques for rational calculation tend to break down. Policy makers seem to adopt strategies that avoid the worst logically possible outcomes, thereby minimizing the maximum possible loss (Mendelhoff, 1979). The position of the Canadian Task Force on pregnancy leaves for VDT operators represents a good example (see Chapter 3, Radiation section).

While the standard of proof required for scientific verification of a hypothesis is quite restrictive, that required for safeguarding rights under the law attempts to make the best decisions on the information that exists. Absolute certainly or even consensus is not required, only the opportunity for all the available evidence to be presented and a fair hearing given to all points of view (Ashford, 1976).

In fact, it is very unlikely that sufficient scientific proof will ever be available or is even possible for some health and safety questions. Particularly with regard to the potential hazard of long term, low level exposure to stressors and conditions, much scientific dispute currently exists and little clarification of the issues is likely to become available in the near future. Too little is now known or is knowable in the short run for scientific proof and definitive standards to be widely forthcoming.

Current health and safety policy is largely oriented toward abatement and control of recognized hazards through government regulation. A recognized hazard is generally considered to be a substance or condition for which the likelihood of harm has been the subject of research giving rise to reasonable suspicion (Ashford, 1979). The burden of proof required to establish this reasonable suspicion as well as that for affirming that current exposures take place at a serious level is borne by the regulatory agency. Health oriented regulatory agencies are also required by law to consider all possible adverse consequences and to minimize the regret by eliminating the most undesirable consequences rather than maximizing the expected rate of return for health benefits (Ashford, 1979).

With these preconditions in mind, there appear to be two major rationales for research. First, scientific studies need to be performed to improve the existing data base about hazards and health effects in order to facilitate understanding, control and preventive measures. A second equally important major rationale for research has more relevance for the processes of health and safety decision making. Research work is crucial to help demonstrate how pervasive problems are. This documentation function is useful to stimulate development of new technologies and control methods. Information dissemination and utilization activities concerning office hazards have been most prominent among labor unions, worker advocacy groups and the popular press. Much of this effort can be characterized as "consciousness raising" although a number of these organizations have distributed guidelines and recommendations for specific hazards. Several unions have conducted training programs or developed training materials. Many of these efforts have been directed specifically at VDT related problems.

Some manufacturers of terminals and furniture have also developed literature and in some cases sponsored research, and recently the Computer and Business Equipment Manufacturers Association (CBEMA) has initiated an information campaign and announced plan to develop an information age institute to aid in the gathering and dissemination of information related to new office technologies.

Information dissemination to related professions such as the American Society of Industrial Designers (ASID), Illuminating Engineers Society (IES), Human Factors Society, American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), National Office Products Association (NOPA), and the Business and Institutional Furniture Manufacturers Association (BIFMA) has depended primarily on industry publications and trade journals. There appears to be little organized activity in any of these organizations to disseminate information. The American Industrial Hygiene Association has conducted several training programs on VDTs and included workshops at annual meetings.

Federal government activities have included sponsorship of a conference on Occupational Health issues affecting clerical/secretarial personnel and a pilot training program on VDTs in addition to a number of publications by NIOSH researchers. NIOSH personnel have also participated in numerous conferences, seminars, and workshops. Information dissemination is largely piecemeal, however. There has been no noticeable activity with respect to office hazards within the Occupational Safety and Health Administration.

It appears that one of the major sources of information, in particular about VDTs, has been trade journals which abound with articles about ergonomic design. These publications as well as newspaper articles are usually oversimplified summarizations of the issues which serve the purpose of alerting various workers and professionals to potential problems but typically do not provide sufficient depth and detail to actually aid in hazard control. In some cases, the effort to simplify the presentation of information has led to inaccurate statements and unsupported conclusions and promises. While such information serves a purpose, it certainly does not satisfy the needs of those professionals who play such an important role in the design of offices. The importance of education has been stressed in one recent report sponsored by the National Office Products Association (NOPA, 1983).

Even in those cases in which accurate and reliable information is presented, it often proves to be of limited use to those attempting to solve practical problems. Typically, a variety of controls are described and users are left to their own resources to determine the appropriate solutions. This is often more difficult than it might appear. Consider the dilemma of an office manager attempting to choose the appropriate office chair from the selection offered by some 100 manufacturers, most of whom now offer some type of "ergonomically" designed chair. The same is true of video display terminals, workstations and glare shields. In the case of noise and lighting controls, users rely almost entirely on vendors.

Another method of disseminating information is through guidelines generated at the corporate level. Again, these efforts have concentrated primarily on the use of VDTs. Typically someone in a safety or health position is given the task of developing guidelines which will be distributed to different offices within the organization. These efforts are often of limited value due to their generality and lack of attention to local conditions, such as environment and job characteristics. These approaches often lead to poor decisions as managers adopt what appear to be standardized solutions without understanding the scope of their problems. It is impossible to determine an adequate control method if the cause of the problem has not been determined. The result of such approaches can be costly and ineffective. The employers who purchase all of the latest ergonomic furniture and improve the lighting but ignore the monotony and monitoring associated with the job may be wasting their time and money.

Another problem which can be encountered when guidelines or standards are followed blindly is employee resistance. This may occur for two reasons. The introduction of changes in the environment, workstation equipment, or methods, which interfere with the worker's performance or are inconsistent with their preferences, are unlikely to be accepted freely. The second reason for resistance may be conflicts with existing collective bargaining agreements. The unilateral imposition of job enlargement or rotation schemes may lead to demands for higher pay consistent with the higher skill level of the redesigned job. In other cases, workers who are satisfied with their current job may object to trading a portion of their job for another employee's boring job.

Market Incentives and Controls

It is often argued that forces within the market will serve to identify and control hazards. While these forces are primarily economic, in that they determine whether a business will remain profitable, they are nevertheless mediated by custom, tradition and a host of other social, cultural and attitudinal characteristics of institutions (Ashford, 1976). Within the context of market force strategies, health and safety essentially becomes a matter of cost and benefit analysis. Some of the negative forces which act within this context are described below.

(1) The direct and indirect costs of injuries, illness and job dissatisfaction, including Workers' Compensation costs, law suits, absenteeism, and labor turnover, all reduce profitability. Workers compensation costs are usually small. For example, the total cost of all workers compensation indemnity payments for 1982 for office clerical workers in Wisconsin is estimated to be $464,548 (Wisconsin, 1983). Extrapolating to the U.S. office clerical work force this would amount to $26.8 million. While this is a fairly large figure, it represents a cost of approximately $1.82 per worker. Product liability suits have become an important market force.

(2) Labor union and worker demands have traditionally played a major role in safety and health. The small percentage of organized labor within the white collar sector (8%) obviously reduces the potential influences of unions, however. Workers can, of course, refuse to work for an employer who provides poor working conditions. This may be a more powerful force than expected (in view of high unemployment rates) since most clerical jobs are low paying. If workers cannot expect to find jobs that pay higher, they may select jobs which provide better working conditions. Labor unions, on the other hand, have often been willing to accept higher wages rather than improved working conditions especially during periods of high inflation. It is interesting to note that when a group of office workers were asked if they would accept lower wage increases in return for improved working conditions 20-30% responded positively (Harris, 1980). An additional 4% of all white collar workers belong to employee associations (nearly all are professional and technical

workers). Such associations may have some influence on the market, especially on office technology issues.

(3) The purchaser can exercise market control by refusing to buy poorly designed or unsafe products. This option is often not exercised, however, either because of lack of knowledge of potential hazards or because of cost considerations.

A number of positive forces can also be identified.

(1) By establishing voluntary consensus standards and encouraging compliance, manufacturers and businesses may be able to avoid government intervention. As an example, the Business and Institutional Furniture Manufacturers Association (BIFMA) has actively participated in developing a variety of performance standards for office furniture safety. The American Society of Heating, Refrigeration and Air Conditioning Engineering (ASHRAE) has developed standards which apply to office temperatures and ventilation. The Illumination Engineering Society (IES) has participated in the development of lighting recommendations for offices. There is also an American National Standards Institute (ANSI) committee on radiation and another has recently been established through the Human Factors Society to draft a technical standard on ergonomic considerations for VDTs. The American Conference of Governmental Industrial Hygienists (ACGIH) has a long history of developing recommendations for exposures to toxic chemicals and other physical agents. There are no comparable activities which deal with issues of job stress or irritating noise. Many of these consensus standards have been adopted by reference or incorporated in federal and state safety and health standards or local building codes.

(2) One of the positive market forces which could potentially provide the strongest incentive to improve office working conditions is productivity. A variety of figures have recently been publicized which indicate that white collar productivity has not increased for a good number of years. Businesses are, therefore, very interested in methods which offer promises for increasing productivity. Office automation and improved working environments are the two most frequently proposed methods. Two recent industry sponsored studies have attempted to address the relationship between productivity and office environments. The first involved a series of studies sponsored by a furniture manufacturer (Harris, 1978, 1980; American Productivity Center, 1982)). The most recent study was conducted by the Buffalo Organization for Social and Technological Innovation (BOSTI), and was supported by grants and contracts from major corporations and government agencies. Only preliminary results from the BOSTI study have been released to date and publication of the complete results are scheduled for late in 1983. The preliminary results do suggest that job satisfaction is definitely influenced by the work environment and in some cases job performance is affected (Westinghouse, 1983).

The failure of market forces to identify and control hazards is one of the major reasons for establishing regulations (Ashford, 1980). A number of imperfections in market forces influence the effectiveness of the system. Most importantly, as with any control strategy, the market cannot control itself if it operates without adequate information. The responsibility for the development of such information becomes the burden of industry. While some large corporations have adequate resources to conduct their own research, the majority do not and thus respond by reacting, often by mimicking the technologies of competitors. While this strategy may respond as quickly as alternative approaches, it is obvious that substantial delays in the development and introduction of technology are often present. For example, the first adjustable VDT workstations were not manufactured in the U.S. until nearly four years after they were described in European reports. Table 4-4 describes user opinions concerning the responsiveness of manufacturers for a number of different office products.

While some would argue that adequate information is already available, several observations serve to demonstrate the difficulties associated with reactive approaches. As was mentioned in a previous section, some 100 different chairs are currently available to purchasers. Most are advertised as being "ergonomically designed." In view of the wide range of features and designs, one has to wonder how they all can be "ergonomically designed." Furthermore, how is the purchaser to know which are most appropriate. While the best may eventually emerge in response to the market, this could be rather ineffective strategy in light of the rather long life of a chair. In view of current costs, they will certainly not be discarded. Similar observations can be made about work tables, lighting systems, VDT screen filters, and VDT screen quality.

Information is also lacking concerning the relationship between specific health problems and their causes, the best example being eyestrain. The employer is faced with the possibility of purchasing a new, higher quality display, redoing the lighting system, purchasing filters, changing the office layout, and providing more frequent rest breaks. These choices must often be made without any assurance that the strategy adopted will actually produce the desired result. It is obvious that market demands must be supplemented by research and training.

TABLE 4-4
Manufacturer's Ability to Keep Pace With End-User Needs As Seen By the End-User

Product	Able to keep up	Somewhat able to keep up	Unable to keep up
Seating	59%	37%	4%
Space dividers	56%	37%	7%
Computer-support furniture	41%	38%	21%
Lighting	29%	53%	18%
Acoustics	22%	50%	28%
Heating and ventilation	12%	60%	28%

*Data taken from study conducted by the National Office Products Association (NOPA, 1983).

A second major disadvantage of reliance on a market system is its inability to respond to the long term effects of low level exposures, unless it is supplemented by research. Other problems associated with market forces include:

1. Market values can be based upon costs which do not consider the personal and social costs of diminished health and well-being;
2. Market forces often fail to identify indirect costs;
3. Control technologies borne purely out of market considerations may not be acceptable to workers. For example, labor unions have frequently expressed doubts about work humanization, quality of work life and similar proposals fearing that their purpose is primarily to increase productivity or diminish the strength of the union;
4. Different technologies may be less favorable to certain industries and in particular small businesses. As a result, they will respond to market forces in different ways. For example, QWL programs, the development of comprehensive manuals, job enlargement and the use of consultants are approaches which might be too costly or risky for small businesses, while unit cost strategies such as ergonomically designed furniture or rest breaks impose more equitable burdens on companies of different sizes.

Table 4-5 provides a summary of some of the relevant problems associated with market based strategies for different potential office.

Manpower Development

The availability of adequately trained personnel is the vital link in any of the three previously described approaches to implementation of hazard

TABLE 4-5

Problems Associated with Market Based Control Strategies

Potential Hazard	Considerations
Air Quality	Most acute effects are measured in terms of discomfort and irritation. Since these symptoms may not lead to lost time, there are seldom and associated worker's compensation costs. Indirect costs associated with respiratory problems and absenteeism, reduced productivity and job dissatisfaction generally go unrecognized. Chronic disorders resulting from long term low-level exposures are difficult to associate with the work environment. The absence of direct costs coupled with potential high cost control methods provide little incentive to assess and correct potential problems.
Temperature/Humidity	Temperature and humidity problems are usually associated only with discomfort and are seldom considered by employers as potential causes of disease. Unless productivity problems can be associated with temperature or humidity problems, there is very little incentive to make potentially costly assessments and improvements.
Musculoskeletal	Musculoskeletal problems associated with poor workstation design have been recognized in recent years, especially where VDTs are used, and have led to compensible injuries and diseases. Furniture manufacturers have responded by providing better designed and adjustable products. Current problems for employers include determining which design features are important and which products are best. The utilization of additional rest breaks in jobs involving constrained postures is considered an unattractive solution due to envisaged losses in productivity.
Vision	Manufacturers of VDTs have provided better designed equipment in recent years in recognition of potential vision problems. Old equipment continues to be used, however, and is seldom replaced for this reason alone. Lighting problems have also been addressed by manufacturers and employers. Some of these problems such as screen reflections and glare affect productivity and are, therefore, more likely to be corrected. Lower lighting levels may also represent energy cost savings. Market forces may have a significant effect in this case.

TABLE 4-5
(Continued)

Potential Hazard	Considerations
Stress	Stress outcomes only rarely affect direct costs (e.g. worker's compensation claims for stress disorders). The indirect costs associated with job dissatisfaction, absenteeism and turnover must be recognized before market forces will take over. Currently, only the largest employers are involved in stress reduction programs. Stress management programs are the most popular.
Noise	Since most sources of noise in offices do not constitute risks to hearing, there are no direct costs. Noise (especially conversation) which effects productivity is often recognized as a problem by employers. Costs associated with controlling noise are potentially high in old open-plan and traditional bull-pen offices and often delay implementation.
Accidents	The total direct costs of accidents in offices is relatively low. Market forces can be expected to have an impact only when a serious accident occurs.
Radiation	While there are methods available which could potentially reduce radiation emissions (including shielding and new technologies such as flat panel displays), the increased costs are not considered justifiable by manufacturers in view of industry and government positions that current radiation emissions do not constitute a hazard.

control strategies. The generation, dissemination and utilization of information all require adequately trained personnel. Regulatory activities depend upon inspectors; and for market forces to operate, hazards must be identified and abated by capable individuals. Obviously, both employees and employers suffer when manpower shortages exist. Unfortunately, there has always been such a shortage, even in the most basic areas of safety and industrial hygiene. For two reasons these deficiencies become even more obvious when office safety and health issues are considered. First, existing personnel are heavily concentrated in manufacturing, construction, and mining industries with interests focused largely on blue-collar workers. Adding office workers to the pool of workers requiring attention nearly doubles the coverage required, further diluting an already deficient supply. Pulling existing manpower away from high hazard industries will be difficult. Secondly, even if it were possible to refocus the attention of safety and health personnel on office hazards, many of these individuals are not adequately prepared to deal with the unique issues raised by office workers.

The same types of personnel are required regardless of occupation or industry, and include: safety professionals, industrial hygienists, medical professionals, ergonomists, industrial psychologists, designers, and engineers. Furthermore, meeting these manpower requirements depend upon an adequate supply of educators supported by sufficient resources and research.

The need for trained professionals will continue to exist among employers, government agencies (both regulatory and consulting), consulting services, product manufacturers, and universities. While a number of universities now offer training in occupational safety and health for professionals, only a few have done much in the area of office health and safety. University research and training depends almost entirely upon government or private funding. Government funding has become more and more limited in recent years and funding for training is currently limited almost entirely to the 15 Educational Resource Centers established by NIOSH.

Most office workers start at a considerable disadvantage since few enjoy the luxury of even having a bona fide safety director. Generally, only those who work in offices supporting industrial, construction, and possibly service industries, have access to safety professionals or industrial hygienists. A few of the larger information industries employ full-time safety and health professionals and these individuals usually reside in corporate offices with only limited contact with the day-to-day problems in the office. As is the case in most small industries, safety and health responsibilities are typically assigned to personnel departments. Outside resources must be relied on extensively in dealing with ergonomics, psychological, job design and medical problems.

It is evident, therefore, that if employers begin to actively deal with occupational health and safety problems, a large proportion of the manpower need will be for consultants in all fields. Most offices will not be able to economically justify employing full-time personnel below the corporate or central office level. This might only be feasible be if there were actually specialists in office safety and health available (trained in all aspects of safety and health). Qualified consultants have become more available in recent years as a variety of management consulting services have anticipated this need and expanded their services. In fact, it may be true at the present time that the supply exceeds the demand. While state government agencies have been providing occupational safety and health assistance to employers, most are not currently prepared to offer the range of services essential in office environments, since most only employ traditional safety professionals and industrial hygienists. In any case, it is doubtful that employers will utilize available consulting services extensively, but will choose to deal with problems by using their own resources. One of the most viable methods of dealing with office health and safety may, therefore, be to increase the expertise of currently utilized manpower and services. Some of these resources include: heating, ventilating and air conditioning engineers, facilities managers, industrial engineers, personnel managers, and data processing managers within the company; and interior designers, engineers, architects, furniture manufacturers and dealers. Table 4-6 lists the type of manpower and resources which could be utilized to deal with different safety and health problems as well as some of the current deficiencies. Increasing the expertise of available manpower resources would depend upon the availability of training for these professionals and services. Numerous professional organizations and trade associations already offer safety and health related services to members. Table 4-7 lists some of these groups and the services currently offered. The extension of some of these services may present a very effective means of reaching a wide variety of individuals who could have a significant impact upon office working conditions.

Another internal source of manpower which has proven to be a viable entity in other industries is the safety and health committees. Such committees are, however, rare in office environments, largely due to the rather low level of unionization within the industry. Union staff and safety committee members who have been able to receive training through their unions or universities have often been able to assist employers in dealing with safety and health problems. Government funding of employee training has also been almost entirely eliminated in recent years, however. Quality of working life committees such as those negotiated by the Communications Workers of America and

TABLE 4-6

Manpower Resources and Related Problems

Potential Hazard	Internal	External	Current Deficiencies
ERGONOMICS (Musculoskeletal, visual, fatigue problems)	industrial engineers facilities managers worker groups	ergonomists physicians nurses industrial engineers lighting engineers product designers office products dealers space planners architects interior designers	- Ergonomists and health professionals are seldom available internally. There is also a shortage of outside consultants. - Industrial engineers and facilities managers lack training in ergonomics. - Lighting engineers, space planners, architects and interior designers lack training in ergonomics.. Need training to balance human needs against cost, efficiency, and esthetic requirements. - Manufacturers of office equipment and furniture have improved ergonomic features but need better and more consistent guidelines. - Office products dealers need training in ergonomics. - Worker groups and unions are not widespread.
INDUSTRIAL HYGIENE (air quality, temperature, ventilation, humidity, noise, radiation)	industrial hygienists maintenance personnel engineers	industrial hygienists heating, ventilating air conditioning engineers	- Industrial hygienists are usually available through outside private groups and government agencies and are rarely utilized by employers. - Engineering and maintenance personnel need training and redirection to address employee health problems. - HVAC designers and engineers need training related to worker health and comfort.

TABLE 4-6
(Continued)

Potential Hazard	Internal	External	Current Deficiencies
STRESS	industrial enginneers QWL committees	psychologists job design experts QWL experts stress management experts industrial engineers	- Stress management, humanization, and job design consultants are available but not extensively utilized. - Industrial engineering emphasis is heavily oriented toward productivity rather than employee well-being. - QWL approaches are usually employed only in large companies.
SAFETY	safety engineers safety and health committees	safety engineers	- Few offices currently have access to safety engineers. Safety and health committees are rare in offices.

TABLE 4-7

Professional Society and Trade Association Services†

Organization	Services and Activities A	B	C	D
American Academy of Safety Education	X		X	
American Association of Industrial Nurses	X	X		
American Conference of Governmental Industrial Hygienists	X	X		X
American Industrial Hygiene Association	X	X		X
American Insurance Association		X		
American Institute of Architects		X		
American Management Association	X			
American Medical Association	X	X		
American National Standards Institute		X	X	
American Public Health Association	X	X		
American Society of Heating, Refrigerating, and Air Conditioning Engineers	X	X	X	
American Society of Safety Engineers		X	X	
Business and Institutional Furniture Manufacturers Association		X	X	X
Computer and Business Equipment Manufacturers Association		X		
Human Factors Society	X	X		
Illuminating Engineering Society	X	X	X	
Industrial Medical Association		X		
Institute of Business Designers	X	X		
National Council on Radiation Protection and Measurements	X		X	
National Office Products Association	X	X	X	X
National Safety Council	X	X	X	X

†This list is not intended to be exhaustive, but represents the range of possible organizations with potential impact on office health and safety. Most of these organizations have state and local affiliates which are especially active in training.

A - Training - includes seminars, tutorials and courses
B - Information - includes responses to inquiries and publications
C - Research - includes sponsoring and conduction research
D - Advisory - includes referrals, consulting services, or information services

Services listed are only those known and may be incomplete. A primary source for this information was Peck (1974).

AT&T also could serve as a means of dealing with office working conditions. While expertise is often needed to evaluate and abate hazards, it is a well recognized fact that employee involvement in problem solving is an important and helpful technique, which can often reduce the impact of professional manpower shortages.

Methods of Overcoming Control Strategy Obstacles

For each of the alternative strategies, a variety of obstacles have been identified. Some are unique to specific methods while others appear to be universal. The most evident obstacle to the development of any approach to controlling office hazards is the absence of adequate information concerning the nature and prevalence of hazards and the effectiveness of control technologies. While a variety of control technologies have been proposed, they are based largely on "expert" opinion rather than scientific data. The most pressing need is for the development of a comprehensive research program. While competitive industries will continue to conduct some of this research, a major burden will obviously fall upon federal agencies, most notably the National Institute for Occupational Safety and Health. The types of research which have been conducted by NIOSH in recent years have been described in Chapter 3. The total projected funds for research on office related hazards in FY 84 are, however, less than $300,000. This amounts to less than one cent per office worker.

The types of research efforts considered necessary fall into several categories:

1. Broad based epidemiological studies are necessary to determine the prevalence of problems. Studies designed to determine the number of

individuals actually exposed to office hazards, typical exposure levels and extreme exposure levels must be carried out. Lacking this type of information, it is virtually impossible to establish appropriate policies for dealing with problems.

2. Practical demonstrations of the relationships between specific risk factors and measurable outcomes must be conducted. With the exception of low-level long-term exposures, such research could provide valuable insights concerning the effectiveness of alternative control technologies. Since many of the problems encountered by office workers involve subjective symptoms (e.g. eyestrain, muscular aches and pains, temperature discomfort, irritating noise, tension, etc.), they lend themselves to rather straight-forward, experimental designs in both laboratory and in field settings since measures of these outcomes can be evaluated in before and after situations when adequate and careful attention is given to control of extraneous factors.
3. While of lower priority, studies of the extent of utilization of various control technologies would be helpful in making policy decisions related to different strategies.
4. Another area of research which could prove fruitful relates to the establishment of quantifiable outcome measures. For example, establishing the relationship between working conditions and measures such as absenteeism and turnover which have directly associated costs could provide a powerful incentive for employers to abate hazards.
5. In view of the widespread interest in productivity in the white collar sector, studies which serve to further substantiate the

relationship between productivity and health and well-being could also provide an incentive to improving working conditions.

6. Research concerning the potential effects of long-term low-level exposures to physical agents and psychological stressors should be carried out on a continuing basis.

The second method of overcoming the obstacles associated with different control strategies involves information dissemination. There is an obvious need to develop the expertise of those responsible for safety and health. This includes employers, manufacturers, vendors, professionals and employees. Models for providing such education already exist, dating back to the years immediately following implementation of the Occupational Safety and Health Act (i.e. training by NIOSH or grants and contracts to labor organizations, labor education programs, professional organizations, and industry). Such an approach could serve to increase the accuracy and usefulness of communicated information. In view of the obvious demand for such information, it would appear that trainees would be willing to bear a substantial portion of the cost. Along with this training, it would also be beneficial to establish a number of resource centers throughout the country which could aid in the collection and dissemination of information, or as an alternative, provide assurance that present NIOSH Educational Resource Centers are adequately addressing the needs of office workers.

A third method of overcoming obstacles would involve the provision of consultative service to small businesses who lack the resources and technical expertise to effectively evaluate and abate hazards. Many state agencies already participate in consultative programs funded by the federal government, although few have done much in the area of office hazards.

Finally, the possibility of providing incentives to manufacturers and businesses deserves consideration. Precedents already exist for some of the incentives. Examples include:

- tax incentives for health and safety research and development,
- accelerated depreciation for new, well-designed equipment,
- low interest loans for work environment improvements.

Incentives might also be used to increase the attractiveness of entering health related fields by providing low interest loans or stipends to students.

Summary

Public concern has resulted in an increased level of consciousness of potential health and safety hazards in offices. It is readily apparent that many of these concerns are well founded and that the level of concern is not about to subside. Many of the hazards faced by office workers are amenable to rather straight forward abatement techniques. In addition, a sufficient number of questions have been raised about long-term low-level exposure effects and potential adverse effects of new technologies to justify concerted research activities. It is evident that government has a role to play in the development of strategies aimed at improving the working conditions of office workers. One of the ways government has traditionally dealt with safety and health hazards is through regulations and enforcement activities. When it can be shown that existing standards are violated, these enforcement activities will come into play. As has been pointed out, many of the problems faced by office workers are not covered by any present standards. The record of the federal government in passing new standards; and the unique nature of many potential office hazards as well as the nature of adverse health effects experienced, would appear to indicate that it is unlikely that any such action will occur at the national level. It is difficult to predict what will happen at the state level.

The federal government could still play an important role outside of regulatory activities. This role would include carrying out and funding research, training programs, and consultative services. Government could also encourage safety and health activities by providing financial incentives. Since such efforts have been minimal in all areas of health and safety in recent years, it is unlikely that any programmatic approaches dealing exclusively with office hazards will be possible. It will, therefore, be necessary to consider office hazards within the context of increased activity in all areas of safety and health.

REFERENCES

ACGIH, TLVs Threshold Limits Values for Chemical Substances in the Work Environment, (Cincinnati, OH: ACGIH, 1983).

American Academy of Opthalmology, Information About Eye Care, (San Francisco: Secretariat for Governmental Relations and Public and Professional Education Committee, 1982).

American Productivity Center, White-Collar Productivity: The National Challenge, (Grand Rapids, MI: Steelcase Inc., 1982).

Arndt, R., "Job Stress Among Telephone Workers," Statistical Report to the Telecommunications International Union, Madison, WI, University of Wisconsin, 1980.

Arndt, R. "Working Posture and Musculoskeletal Problems of Video Display Terminal Operators-Review and Reappraisal," Am. Ind. Hyg. Assoc. J., 44(6):437-446, 1983.

Ashford, N.A., Crisis in the Workplace: Occupational Disease and Injury, (Cambridge, Mass.: MIT Press, 1976).

Ashford, N. A., "Federal Control of Toxic Substances in the Environment and Workplace: Legal, Regulatory and Scientific Complexities," in Public Control of Environmental Health Hazards , E.C. Hammond and I. K. Selikoff, eds., (New York: New York Academy of Sciences, 1979).

Ashford, N. A., "The Benefits of Environmental Health and Safety Regulation," Hearings of the U.S. Senate Committee on Governmental Affairs, 96th Congress, 2nd session, Washington D.C., March 25, 1980.

ASHRAE 55-81, Thermal Environmental Conditions for Human Occupancy, (Atlanta, GA.: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1981).

ASHRAE 62-73, Standards for Natural and Mechanical Ventilation, (Atlanta, GA.: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1973).

ASHRAE 62-81, Ventilation Required for Acceptable Indoor Air Quality: Standard 62-81, (Atlanta, GA.: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1981).

ASHRAE Handbook, Fundamentals Volume,1981, (Atlanta, GA.: American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1981).

ASHRAE, "Position Statement on Indoor Air Quality," ASHRAE Journal 45-47, August, 1982.

Baldwin, D., "Caution: Office Zone," *Job Safety and Health,* 4(2):4-12, 1976.

Bear, J. D. N., and Richler, A., "Environmental Influences on Ocular Refraction," *Amer. J. Epid.,* 115:138-139, 1982.

Billings, C. E., and Vanderslice, S. F., "Methods for Control of Indoor Air Quality," *Environ. Internatl.,* 8:497-504, 1982.

Bird, F. E., "Safety," Chapter 47, in *The Industrial Environment-Its Evaluation and Control,* (Washington D.C.: HEW, 1973).

Blundell, G. S., "Personal Computers in the 80s," *Byte,* 166-182, Feb., 1983.

Blundell, G. S., "Personal Computers: The 12 Most Asked Questions," *Data Management,* 26E-26J, Oct., 1982.

Brodeur, P., Presentation given at "Dangers and Hazards of Video Display Terminals," Healthwriters Conference, Madison, WI, 1983.

Bureau of Radiological Health, *Regulations for the Administration and Enforcement of the Radiation Control for Health and Safety Act of 1968,* U.S. Department of Health and Human Services, Food and Drug Administration, Publ. 80-8035, July, 1980.

Bureau of Radiological Health, U.S. Department of Health and Human Services, Food and Drug Administration, *An Evaluation of Radiation Emissions from Video Display Terminals,* HHS Publication no. FDA 81-8153 Rockville, MD., 1981.

Bureau of the Census, *Statistical Abstracts of the United States 1982-1983,* 1983.

Business Week, "A New Era for Management," April 25, 1983.

Business Week, "The Shrinking of Middle Management," April 25, 1983.

Byrd, E., reported in "Warnings Sounded on ELF Emissions," in *The Guild Reporter,* XLIX(12), June 18, 1982.

Cakir, A., Reuter, H., von Schmudt, L., et al., *Research into the Effects of Video Display Workplaces on the Physical and Psychological Function of Persons* (Bonn, West Germany: Federal Ministry for Work and Social Order, 1978).

Cakir, A., Hart, D. J., and Stewart, T.F.M., *Visual Display Terminals,* (New York: John Wiley and Sons, 1980).

Canadian Labour Congress, *Towards a More Humanized Technology: Exploring the Impact of VDTs on the Health and Working Conditions of Canadian Office Workers,* (Ottawa, Ont.: Labour Education and Studies Center, 1982).

Carey, M., "Three Paths to the Future: Occupational Projections, 1980-90," Occup. Outlook Quart., 3-11, 1981.

Carroll, J. C., "Technology and Job Pressures," in Machine Pacing and Occupational Stress, G. Salvendy and M.J. Smith, eds., (London: Taylor and Francis, 1980).

Channer, S. D., "The Case for Furniture Befitting the Human Condition," Modern Office Procedures, 53-60, June, 1983.

Chicago Tribune, "Eye Panel Urges Annual Check-ups for VDT Users," Oct., 23, 1983.

Coe, J. B., Cuttle, K., McClellan, W. C., et al, Visual Display Units, (Wellington, New Zealand: Department of Health Report W/1/80, 1980).

Colligan, M. J., Smith, M. J., and Hurrell, J. J., "Occupational Incidence Rates of Mental Health Disorders," J. Hum. Stress, 3(3):34-39, 1977.

Cooper, C.L., and Payne, R., eds., Stress at Work, (New York: John Wiley and Sons, 1978).

Cooper, C.L., and Payne, R., eds., Current Concerns in Occupational Stress, (New York: John Wiley and Sons, 1980).

Cox, E. A., "Radiation Emissions from Visual Display Units," in Health Hazards of VDUs, Vol. 1, Papers presented at HUSAT Conference,(Loughborough: Loughborough University of Technology, 1980).

Cyr, N. J., "Improved Productivity Through Computerized Memomotion," Ind. Eng., 11:34-39, 1979.

Dainoff, M. J., Happ, A., Crane, P., "Visual Fatigue and Occupational Stress in VDT Operators," Hum. Fact. 23:421-437, 1981.

Dataquest Inc., Personal Communication, 1983.

Davenport, J. "What Ever Happened to QWL?" Office Admin. and Autom., 26ff., May, 1983.

Desnoyers, L., and LeBorgne, D., Vision et Travail, Bull. 20, (Montreal, Can., Institut de Recherche Appliquee sur le Travail, Sept., 1982).

Dickerson, B., "Human Factors: An IBM Perspective," NIOSH Conference on Occupational Health Issues Affecting Clerical/Secretarial Personnel, Cincinnati, OH, July 21-24, 1981.

Elias, R., Cail, F., Tisserand, M., et al., "Investigations in Operators Working with CRT Display Terminals: Relationships Betweeen Task Content and Psychophysiological Alterations in, Ergonomic Aspects of Video Display Terminals, E. Grandjean and E. Vigliani, eds., (London: Taylor and Francis, 1980).

Etelman, K., "For the Biggies, Micros are the Right Fit," *Data Management*, 26K-26M, Oct., 1982.

Fanger, D. O., and Valbjorn, O., eds., *Indoor Climate*, (Copenhagen, Den.: Danish Building Research Institute, 1979).

Faust, H., and Brilliant, L., "Is the Diagnosis of Mass Hysteria an Excuse for Incomplete Investigation of Low Level Environmental Contamination," *J. Occup. Med.*, 23(1):22-26, Jan., 1981.

Ferrand, E. F., and Moriates, S., "Health Aspects of Indoor Air Pollution: Social, Legislative, and Economic Considerations," *Bull. N. Y. Acad. Med.*, 57(10):1061-1066, Dec., 1981.

Fielding, J. E., "Preventive Medicine and the Bottom Line," *J. Occup. Med.*, 21(2):79-88, Feb. 1979.

Frank, A. L., *Effects on Health Following Occupational Exposure to Video Display Terminals*, (Lexington, Kentucky: University of Kentucky, 1983).

Glasar, Z., "Basis for the NIOSH Radio Frequency and Microwave Criteria Document," *Proc. ACGIH Topical Symposium-Non-Ionizing Radiation*, Nov. 26-28, 1979.

Gould, J. D., and Grischkowsky, N., *Doing the Same Work With Hard Copy and Cathode Ray Tube (Computer Terminals)*, (Yorktown Heights, NY: IBM Research Center, 1983.

Government Accounting Office, *Advances in Automation Prompt Concern Over Increased U.S. Unemployment*, Staff Study AFMD-82-44, May 25, 1982.

Green, G. H., "The Positive and Negative Effects of Building Humidification," 1049-1060, 1982.

Gregory, J., "Results from Working Women's Office Worker Health and Safety Survey," NIOSH Conference on Occupational Health Issues Affecting Clerical/Secretarial Personnel, Cincinnati, OH, July 21-24, 1981.

Gregory, J. Personal communication, 1983.

Gunnarsson, E., Ostberg, O., *Physical and Mental Working Environment in a Terminal-based Data System*, (Stockholm: Industrial Welfare Council, Research Report Vol. 35, 1977).

Gunnarsson, E., and Soderberg, I., *I. Eyestrain Resulting from VDT Work at the Swedish Telecommunications Administration*, (Stockholm: National Board of Occupational Safety and Health, Staff Conference, 1980).

Guttormmson, U., and Smith, R., *Attityder till Primielon inom Postbanken*, (Stockholm: Rapport till Statstjanstemannaforbundet, 1971).

Hammer, W., Occupational Safety Management and Engineering, (Englewood Cliffs: New Jersey: Prentice-Hall, 1976).

Harris, Lewis and Associates, The Steelcase National Study of Office Environments: Do They Work? (Grand Rapids, MI: Steelcase Inc, 1978).

Harris, Lewis and Associates, The Steelcase National Study of Office Environments, No. II: Comfort and Productivity in the Office of the 80s, (Grand Rapids, MI: Steelcase Inc., 1980).

Haynes, S. G., and Feinleib, M., "Women, Work and Coronary Heart Disease: Prospective Findings from the Framingham Heart Study," A.J.P.H. :70(2):133-141, Feb., 1980.

Health Education and Welfare, Work in America, (Cambridge, MA: MIT Press, 1980).

Helander, M. G., Billingsley, P. A., Schurick, J. M., Critical Review of Human Factors Research on Visual Display Terminals, Tech. Report CRG-82-004, (Westlake Village, CA: Canyon Research Group, July, 1982).

Hileman, B.,"Indoor Air Pollution," Environ. Sci. Technol., 17(10):469-472, 1983.

Hirshfelder, D., "Better Industrial Vision Testing and Safety," Occupational Health and Safety, 49:30-34, 1980.

Howard, H. P., and Rothstein, D. E., "Up Up Up and Away: Trends in Computer Occupations" Occupational Outlook Quart. Summer:3-11, 1981.

Hunting , W., Laubli, Th., Grandjean, E., "Constrained Postures of VDU Operators"as cited in E. Grandjean, "Ergonomics of VDUs: Review of present knowledge" in Ergonomic Aspects of Video Display Terminals , E. Grandjean and E. Vigliani, (London, Taylor and Francis, 1980).

Hunting, W. T., Laubli, Th., Grandjean, E., "Postural and Visual Loads at VDT Workplaces, I. Constrained Postures," Ergonomics, 24(12):917-931, 1981.

ILO-WHO, Joint ILO-WHO Committee on Occupational Health, WHO Technical Report Series 66, 1962.

International Data Corporation, Framingham, MA, Personal Communication, 1983.

Johansson, G., and Aronsson, G., Stress Reactions in Computerized Administrative Work, (Stockholm: Department of Psychology, U. of Stockholm, 1980).

Keeling, B., Kallaus, N., and Neuner, J., Administrative Office Management, 7th ed.(Southwestern Publishing Company, 1978).

Kilgour, J. G., "Union Organizing Activity Among White Collar Employees," *Personnel,* 18-27, Mar.-Apr., 1983.

Kirchner, E., "At the Mercy of Machines," *Datamation,* 254-261,Sept., 1982.

Kish, J. L., "Auditing Word-Processing, Productivity and Performance," *Nat. Prod. Rev.,* 427-436, Autumn, 1982.

Kogi, K., "Finding Appropriate Work-Rest Rythym for Occupational Strain on the Basis of Electromyographic and Behavioral Changes," in *Kyoto Symposia (EEG Suppl. 36),* P. A. Buser, W. A. Cobb and T. Okuma, eds.,(Amsterdam: Elsevier Biomedical Press, 1982).

Kuehner, R. L., "ASHRAE Research Report No. 1569-Humidity Effects on the Odor Problem" *ASHRAE Trans.,* 62:249, 1956.

Labour Canada Task Force, *In the Chips: Opportunities, People, Partnerships,* (Ottawa, Ont.: Minister of Labour, 1982).

Laubli, Th., Hunting, W., and Grandjean, E., "Visual Impairments Related to Environmental Conditions in VDU Operators," as cited in E. Grandjean, "Ergonomics of VDUs: Review of Present Knowledge," in *Ergonomic Aspects of Video Display Terminals* , E. Grandjean and E. Vigliani, eds., (London: Taylor and Francis, 1980).

Learner, E., "Radio Frequency Radiation: Biological Effects," *IEEE Spectrum,* Dec., 1980.

Leon, C. B., "Occupational Winners and Losers: Who They Were During 1972-80," *Monthly Labor Review,* 18-28, June, 1982.

Levi, L., "Stressors, Stress Tolerance, Emotions and Performance in Relation to Catecholamine Excretions" in *Emotional Stress: Physiological and Psychological Reactions, Medical, Industrial, and Military Implications,* L. Levi, ed. (New York: American Elseaier, 1967).

Levi, L., "Stress and Distress in Response to Psychosocial Stimuli," *Acta Medica Scandinavica,* (Supp. 528, 1972).

Levitan, S. A., and Johnson, C. M., "The Future of Work: Does it Belong to Us or the Robots?" *Monthly Labor Review,* 10-14, Sept., 1982.

Linden, V., Rolfsen, S., "Video Computer Terminals and Occupational Dermatitis," *Scand. J. of Work and Environ. Health,* 7:62-67, 1981.

Marsh, P., "Britain Faces Up to Information Technology," *New Scientist,* 9:634-638, Dec., 1982.

Marshall, E., *Science,* 212(4449):1120-1121, June 5, 1981.

Mendelhoff, J. *Regulating Safety: An Economic and Political Analysis of Occupational Safety and Health,* (Cambridge, Mass.: MIT Press, 1979).

Meyer, B., *Indoor Air Quality,* (Reading, MA, Addison-Wesley, 1983).

Meyer, N. D., "The Role of Management Science in Office Automation," *Interfaces,* 10:72-76, 1980.

Microwave News, 9-11,Nov., 1983.

Miksch, R. R., Hollowell, C. D., and Schmidt, H. E., "Trace Organic Chemical Contaminants in Office Spaces," *Environ. Internat.* 8:129-137, 1982.

Mills, D. Q., "Human Resources in the 1980s," *Harvard Bus. Rev.,* July-August: 154-162, 1979.

Moss, C. E., Murray, W. H., Parr, W., et al., *A Report on Electromagnetic Radiation Surveys of Video Display Terminals,* (Cincinnati,OH: HEW NIOSH, 1977).

Murphy L. R., and Hurrell J.J., "Machine Pacing and Occupational Stress," in *New Developments in Occupational Stress, UCLA Conference Proceedings,* R. M. Schwartz, ed. (Cincinnati, OH: DHEW NIOSH, 1979).

Murray, W. E., Moss, E., Parr, W. H., et al., "Radiation and Industrial Hygiene Survey of Video Display Terminal Operations," *Hum. Fact.,* 23:413-420, 1981.

Nardone, T., "The Job Outlook in Brief," *Occupational Outlook Quarterly,* 2-6, Spring,.1982.

National Research Council Committee on Indoor Pollutants, *Indoor Pollutants,* (Washington, D.C.: National Academy Press, 1981).

National Research Council, *Video Displays, Work, and Vision,* (Washington, D.C.: National Academy Press, 1983).

New York Stock Exchange, *People and Productivity: A Challenge to Corporate America* (New York: New York Stock Exchange, 1982).

New York Times, "Reagan Plan on Hazards Draws Fire," Nov. 10 1983.

NOPA, *The Future of the Office Furniture Industry,* (Alexandria, VA,: National Office Products Association, 1983).

Occupational Hazards, "Sick Building Syndrome-The Search for a Cure," Oct., 1983.

Occupational Safety and Health Act, Public Law 91-596, 91st Congress, December 29, 1970.

Olson, M. H., and Lucas, H. C., "The Impact of Office Automation on the Organizastion: Some Implications for Research and Practice," *Commun. of the ACM,* 25(11):838-847, Nov., 1982.

Ostberg, O., Towards Standards and TLVs for Visual Work, Tech. Report 37T, (Lulea,Sweden: Department of Human Work Sciences, University of Lulea, 1977).

Otson, R., Doyle, E. E., Williams, D. T., et al, "Survey of Selected Organics in Office Air," Bull. Environ. Contam. Toxicol. 31:222-229, 1983.

Panko, R., "Facing Basic Issues in Office Automation," Computer Networks, 5:391-399, 1981.

Peck, T. P., Occupational Safety and Health: A guide to Information Resources, (Detroit: Gale Research, 1974).

Peterson, R. C., Weiss, M. M., and Minnaci, G., "Nonionizing Electromagnetic Radiation Associated with Video Display Terminals," in Ocular Effects of Non-ionizing Radiation, Bellingham WA, Society of Photo-Optical Instrumentation Engineers,229:179-186, 1980.

Repace, J. L., "The Problem of Passive Smoking," Bull. N. Y. Acad. Med. 57(10):936-946, Dec., 1981.

Rycroft, R. J. G., and Smith, W. D. L., "Low Humidity Occupational Dermatoses," Contact Dermatitis 6:488-492, 1980.

Sadlier, C. D., "Office of the Future-New Challenges for Operations Research," Omega, 8(1):21-28, 1980.

Saffady, W., The Automated Office: An Introduction to the Technology (Silver Springs, Md.: National Micrographics Association, 1981).

Sauter, S. L., Arndt, R., and Gottlieb, M., "A Controlled Survey of Working Conditions and Health Problems of VDT Operators at the New York Times," University of Wisconsin, Madison, 1981.

Sauter, S. L., Gottlieb, M., and Jones, K. C., "A General Systems Analysis of Stress/Strain in VDT Operations," paper presented at Conference on Human Factors and Computer Systems, Gaithersburg, MD, 1982.

Slesin, L., and Zybko, M., Video Display Terminals: Health and Safety Excerpts from Microwave News, (New York: Microwave News, 1983).

Smith, A. B., Tanaka, S., Halperin, W., et al., "Cross Sectional Survey of VDT Users at the Baltimore Sun," (Cincinnati, OH: NIOSH, 1982).

Smith, M. J., "Health Issues in VDT Work," (Cincinnati, OH: NIOSH, 1982).

Smith, M. J , Cohen, B. G. F., Stammerjohn, L. W., and Happ, A., "An Investigation of Health Complaints and Job Stress in Video Display Operations," Hum. Fact. J., 23(4):387-400, 1981.

Snyder, H., "Vision and the VDU," *Health and Ergonomic Considerations of Visual Display Units-Symposium Proceedings,* (Akron,OH: American Industrial Hygiene Association, 1983).

Spencer, G., Long J. F., "The New Census Bureau Projections," *Amer. Demographics,* 24-31, April, 1983.

Springer, T. J., *Video Display Terminal Workstations: A Comparative Evaluation of Alternatives,* State Farm Mutual Automobile Insurance Company, 1982.

Starr, S. J., Thompson, C. R., Shute, S. J., "Effects of Video Display Terminals on Telephone Operators," *Hum. Fact.,* 24(6):699-711, 1982.

Sunflex Inc., Personal Communication, 1983.

Taylor, F. W., *The Principles of Scientific Management,* (New York: Harper and Bros., 1911).

Taylor, H. R., "The Author Replies," *Amer. J. Epid.,* 115:139-142, 1982.

Thorne, M., "Office Equipment: Electronics Empties the Typing Pool," *Nations Business,* Feb., 1979.

Time, "Stress: Can We Cope?" June 6, 1983.

Wall Street Journal, "Age of Anxiety," April 2, and April 16, 1979.

Weiss, M. M., "The Video Display Terminals-Is There a Radiation Hazard?" *J. Occup. Med.,* 25(2):98-100, 1983.

Weiss, M. M., and Petersen, R. C., "Electromagnetic Radiation Emitted from Video Computer Terminals," *Am. Ind. Hyg. Assoc. J.,* 40:300-309, 1979.

Wernecke, D., *Microelectronics and Office Jobs: The Impact of the Chip on Women's Employment,* (International Labour Office, 1982).

Westinghouse Open Office Systems, *The Impact of Office Environment on Productivity and Quality of Working Life,* 1983.

White, I. R., and Rycroft, R. J. G., "Low Humidity Occupational Dermatoses-An Epidemic," *Contact Dermatitis,* 8:287-290, 1982.

Whycer, B., "A Simple Screening Technique for Visual Assessment," in *Visual Aspects and Ergonomics of Visual Display Units,* V. M. Reading, ed., (London: Institute of Opthalomology, U. of London, 1978).

Wisconsin, State of, *Supplementary Data System Occupational Injury and Illness Data, 1982,* Department of Industry, Labor and Human Relations, Workers' Compensation Division, Oct., 1983.

Wolbarsht, M. L., and O'Foghludhr, F. A., Sliney, D. H., et al., "Electromagnetic Emissions from Visual Display Units: A Non-Hazard, in *Ocular Effects of Non-Ionizing Radiation,* M. L. Wolbarsht and D. H. Sliney, eds., Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 229, Bellingham, WA., 1980.

Wolfbein, S. L.,"Planning for the U. S. Labor Force of the '80s'," *National Productivity Review,* Spring:228-239, 1982.

Zaret, M. M., "Cataracts and Visual Display Units," *Health Hazards of VDUs?* HUSAT Research Group, Loughborough, UK: University of Technology, 1980).

Zisman, M. D., "Office Automation: Revolution and Evolution," *Sloan Mgmt. Rev.,* Spring:1-16, 1978.

CARPAL TUNNEL SYNDROME

A Case Study

Margit L. Bleecker, M.D., Ph.D.
The Johns Hopkins Medical Institutes

May 1984

Health Program
Office of Technology Assessment
U.S. Congress

Table of Contents

Introduction..1

Definition of Carpal Tunnel Syndrome.................1

Occupational Activities Associated with
Carpal Tunnel Syndrome.............................1

Background..2

Historical..2

Carpal Tunnel Syndrome in Industry Today............5

Table 1...7

Anatomy of Carpal Canal....................................8

Description of the Carpal Canal and Its Contents....9

Figure 1...9

Clinical Presentation of Carpal Tunnel Syndrome.........10

Common Presenting Complaints.........................10

Physical Examination.....................................12

Ancillary Diagnostic Tests...................................13

Nerve Conduction Studies (Electromyogram)..........13

Vibration Threshold. 14

Pneumatic-Tourniquet Test..............................15

Thermography...16

Pathophysiology...16

Etiology of Carpal Tunnel Syndrome.......................18

Decrease of Cross Sectional Area of Carpal Canal...18

Enlargement of the Median Nerve.......................18

Increase Volume of Contents in the Carpal Canal....19

Factors Responsible for the Development of

Carpal Tunnel Syndrome in the Workplace............19

Work Method..19

Vibration..21

Hand Tool Design.....................................21

Hobbies..22

Conditions Associated with Carpal Tunnel Syndrome.......22

Systemic Diseases or Conditions Associated with Carpal Tunnel Syndrome.........................22

Conditions Associated with Carpal Tunnel Syndrome in the Workplace.....................22

Other Conditions Confused with Carpal Tunnel Syndrome..............................23

Treatment of Carpal Tunnel Syndrome.....................23

Cases of Carpal Tunnel Syndrome Studied at the Neurometric Laboratory at Baltimore City Hospitals in 1982..................................27

Medical Surveillance of Workers for Carpal Tunnel Syndrome...................................28

Table II...

Table III..

References...31

CARPAL TUNNEL SYNDROME - CASE STUDY

1. INTRODUCTION

Some twenty million workers on assembly lines and in other jobs that require repetitive, strain producing motions are at an increased risk for the development of carpal tunnel syndrome (CTS). Because the musculoskeletal strain from repeatedly flexing the wrist or applying arm-wrist-finger force does not cause immediately observable injuries, it often takes months or even years for workers to detect damage (Occupational Health and Safety, 1981). The overall incidence rate and prevalence of carpal tunnel syndrome in the work force is not yet known.

A. Occupational Activities Associated With Carpal Tunnel Syndrome

- Aircraft
- Automobile Assembly
- Buffing
- Coke Making
- Electronic Asssembly
- Fabric Cutting/Sewing
- Fruit Packing
- Gardening
- Hay Making
- Waitressing
- Housekeeping
- Assembly Inspecting
- Meat Processing
- Metal Fabricating
- Musicians
- Packaging
- Postal Workers
- Textile Workers
- Tire and Rubber Workers
- Typing
- Upholstering

B. Definition of Carpal Tunnel Syndrome

CTS results from compression (pinching) or irritation of the median nerve as it passes into the hand between the carpal bones and the transverse carpal ligaments. It results in discomfort and impaired use of the hand.

II. BACKGROUND

A. Historical

In 1365, Sir James Paget described a case of latent impairment of the median nerve subsequent to an old fracture of the wrist in his lectures on surgical pathology. This case was the first of its type to be reported and the condition could be classified today as median-nerve compression or carpal tunnel syndrome.

The first of Marie's patients in 1891 with acromegaly was described as having "weakness" of the left hand and a tingling sensation (Marie, 1891). Although the carpal tunnel syndrome was not fully recognized until many years later (Woltman, 1941; Cannon and Love, 1941; Brain et al, 1947), this patient probably was an early example. Interestingly, the first autopsy description of median entrapment was also made by Marie and Foix in 1913. They even suggested that patients with thenar paralysis should be treated by sectioning of the transverse carpal ligament. It appears, however, that there was an inordinate delay in carrying out their suggestion, because the first successful report of surgical relief of the carpal tunnel syndrome was not made until 1941 (Woltman, 1941).

Ramsy Hunt (1911) drew attention to the syndrome which he described as "the thenar (thumb) type of neural atrophy of the hand" The limitation of wasting to intrinsic muscles of the hand controlling thumb movement led Hunt to place the lesion in the thenar branch of the median nerve where it passes beneath the transverse carpal ligament.

Brouwer (1920) reported 14 cases. His first 4 patients were tailors; 2 of his female patients did much washing, and 3 had arthritis. Brouwer

Reproduced from
best available copy.

emphasized the importance of occupation and considered that the thenar muscles, being of recent phylogenetic development, were especially liable to undergo degeneration as a result of trauma.

Harris (1926) described wasting of the thenar muscles due to neuritis of the median nerve caused by intermittent pressure on the ball of the thumb by an instrument such as a trowel-handle or a scrubbing brush.

Dorndorf (1931) reported 16 cases of isolated paralysis of the ball of the thumb. All of his patients were women at or near the menopause. He was inclined to attribute the disorder to ischemia, without reaching a conclusion about the site of the lesion.

Moersch (1938), who reported another case, accepted Hunt's view that the motor branch was injured as it passed over the distal edge of the anterior carpal ligaments.

Wartenberg (1939) reported 7 cases of "partial thenar atrophy". He observed that the thenar branches of the median nerve may be so unfavorably placed in a normal person as to be subject to trauma by the ordinary use of the hand. Nevertheless, he concludes that the evidence that such is the cause of the thenar atrophy is unconvincing. The occurrence in some patients of paraesthesias (pins and needles sensation) not necessarily confined to the distribution of the median nerve suggests the presence of some unknown noxious factor to which Wartenberg supposes the thenar muscles to be specially susceptible owing to their late development in the evolution of man.

Woltman (1941) reported 2 cases of median neuritis with both motor and sensory symptoms. The first patient had acromegaly, and her hands eventually improved after x-ray treatment of the pituitary. The second patient had unilateral median neuritis, secondary to arthritis of the wrist, with motor, sensory, and trophic symptoms which disappeared after section of the transverse carpal ligament.

Zachery (1945) reported 2 cases, one in which x-rays showed old fractures of both scaphoids, with osteoarthritis and the second had an old malunited colle's fracture.

Brain et al. (1947) described the clinical presentation of six women with burning and tingling sensations in the distribution of the median nerve in the hand. No bony lesions were shown radiographically. There was little doubt that occupation was a causal factor. One was employed in tailoring, while the other five were performing much unaccustomed housework. Further exploration by Brain et al. using cadaver studies demonstrated that in acute flexion of the wrist to a right angle the pressure within the carpal canal was elevated by 100 mm of water, while in extension to a right angle it was raised to well over 300 mm of water. Considering that extension, especially repeated extension, was a common movement in housework, it was concluded that the rise of pressure in the carpal tunnel caused by repeated extension of the wrist was, in some people, sufficient to cause compression of the median nerve.

Kremer et al. in 1953 stated that median-nerve compression in the carpal canal was the main cause of the syndrome long known as "acroparesthesia," which affects women in middle life, and is characterized by pain and paresthesia in one or both hands, which is worse at night.

In 1957, Heathfield wrote that many neurologists accepted this view, but others still thought that acroparesthesia may be due to other causes, such as cervical spondylosis, the thoracic outlet syndrome, or that it was an entity in itself. Therefore, to summarize, in these initial case descriptions of CTS, the majority occurred in middle aged or elderly women often not

Reproduced from best available copy.

associated with evidence of bony damage in the neighborhood of the wrist-joints. The symptoms were pain, paresthesias, and cutaneous sensory loss within the distribution of the digital branches of the median nerves, and partial thenar atophy, limited to muscles of the thumb within the hand (abductor brevis and opponens pollicis). At surgery the lesion was compression of the median nerve in the carpal tunnel with edema for 1 inch proximally. The causal relationship to occupation was already appreciated with these initial descriptions of CTS.

In 1966, Phalen reviewed his own experience with CTS after operating over a 17 year period on more than 650 patients for CTS. He believed that thickening or fibrosis of the flexor synovialis (sheath around the long flexor tendons in the carpal tunnel) within the carpal tunnel was the most common cause of the syndrome. In his series the ratio of women to men was 3:1 with the women at or near the menopause. Mention of systemic disorders associated with CTS such as acromegaly, myxedema, arthritis and diabetes was included but a causal relationship to any occupation was omitted.

B. Carpal Tunnel Syndrome in Industry Today

> "Various and manifold is the harvest of diseases reaped by certain workers from the crafts and trades that they pursue; all the profit that they get is fatal injury to their health....mostly, from two causes. The first and most potent is the harmful character of the materials that they handle....the second cause I ascribe to certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom." -- Ramazzini (1717)

Needless to say the second cause still exists two hundred and sixty years later with the carpal tunnel syndrome one of the most frequent outcomes. The overall incidence rate and prevalence of carpal tunnel syndrome in the work force is not yet known.

Indirect approximations of prevalence for CTS has been cited in the literature. Shapiro et al. (1982) evaluated 298 male dentists for mercury exposure. The 23 dentists who had the highest mercury levels biologically were administered standardized electrodiagnostic tests revealing 22 percent to have CTS. In a second study of dentists examined for nitrous oxide neurotoxicity, 10 percent of the 19 dentists had symptoms and nerve conduction studies suggestive of CTS (Dyck et al., 1980). A third group of construction workers performing burning operations on steel structures showed a 55 percent prevalence of CTS. The unusually high prevalence of nerve entrapment in these lead exposed workers was felt to be due to nerve (endoneurial) edema resulting from their toxic exposure (Bleecker, in press). Additional prevalence figures for General Services Administration (GSA) workers who use light to medium tools was 14 percent (Bleecker and Birke, in press) and 11 percent for electricians in GSA switchgear operations (Emmett, 1983).

TABLE 1

Working Category	Total # of Employees Examined	Prevalence of CTS
1. General Service Administration (GSA) workers	141	14%
2. Electricians	55	11%
3. Workers overexposed to lead	31	55%
4. Dentists exposed to mercury	23	22%
5. Dentists exposed to nitrous oxide	19	10

Other prevalence figures for CTS are not specific for the syndrome. The National Institute for Occupational Safety and Health (NIOSH) states that 15 - 20 percent of workers employed in construction, food preparation, clerical work, production fabrication, and mining are at risk of developing cumulative trauma disorders. Unfortunately, the National Occupational Hazard Survey includes CTS, tendonitis, ganglionitis, tenosynovitis, bursitis, and epicondylitis as cumulative trauma disorders (NIOSH, 1977). This statistic does not include strict diagnostic criteria or a completely defined population of workers. The Bureau of Labor Statistics (1982) indicates that 23,200 occupational injuries were associated with repeated trauma in 1980; however, this data encompasses no denominator and is not limited to CTS related diagnosis.

Similar data were reported by Hymovich and Lindholm (1966) in their description of electronics assembly and bench work in a Connecticut electronics firm where 62 repetitive trauma disorders of the hand and wrist occurred during 960 worker years (6.4 cases per 200,000 work hours). The disorders included: ganglionic cysts, tenosynovitis and CTS.

Wherle (1976) reported an average of 2.1 cases of CTS per 200,000 work hours from 1971 through 1975 in an auto upholstery plant with approximately 1,000 employees. On some jobs, incident rates were as high as 25.6 per 200,000 work hours.

III. ANATOMY OF CARPAL CANAL

Carpal tunnel syndrome is a specific form of pressure [illegible] nerve injury results from compression by neighboring [illegible] The carpal canal or tunnel is formed by the concave arch of the carpal bones (scaphoid, greater multangular, pisiform, hook of the hamate, lesser multangular, and capitate) and is roofed by the transverse carpal ligament (see figure 1). These structures form a rigid compartment through which nine tendons and the median nerve must pass. Any compromise of this unyielding space usually compresses the median nerve. In a detailed anatomical study by Robbins (1964) the median nerve was shown to be flattened, lying immediately under the transverse carpal ligament. The transverse carpal ligament had a fusiform thickening most prominent in the mid portion of the canal. The median nerve in its position immediately deep to the transverse carpal ligament was seen to become progessively flattened as the ligament thickens, the maximum flattening occurring by the capitate (one of the carpal bones). The cross sectional area of the carpal tunnel decreases from its entrance to a point between 2.0 and 2.5 centimeters distal to its inception. It then increases in area. The effect is to have a canal with a slightly narrowed waist.

All the structures are crowded into the canal. However, with the wrist in neutral position, the carpal tunnel easily permits the passage and withdrawal of a long, flattened piece of rubber, measuring 6 mm wide by 2 mm thick. Withdrawal of the piece of rubber, inserted directly beneath the transverse carpal ligament, becomes more difficult as the degree of extension or volar flexion of the wrist is increased. It is held more tightly in the hyperextended than in the acutely volar flexed position. Abbott and Saunders (1933) stated that, even in normal persons, acute volar flexion of the wrist pinches the median nerve between the proximal margin o. the transverse carpal ligament and the bones in the forearm.

Characterization of overall hand size was tabulated by Armstrong and Chaffin (1979) in a group of workers with CTS and a group of controls. Anthropometric data was collected from surface measurement of the hand and wrist including external measurements of hand length, palm width, wrist width and wrist thickness and the internal dimension of third metacarpal length were selected for characterization of overall hand size. No significant differences between the two groups was found. Even when several internal measurements were made from x-rays to estimate the carpal angle, which is the curvature of the carpal bones, no association was found between hand shape and CTS.

FIGURE 1.: Anatomy of Carpal Canal

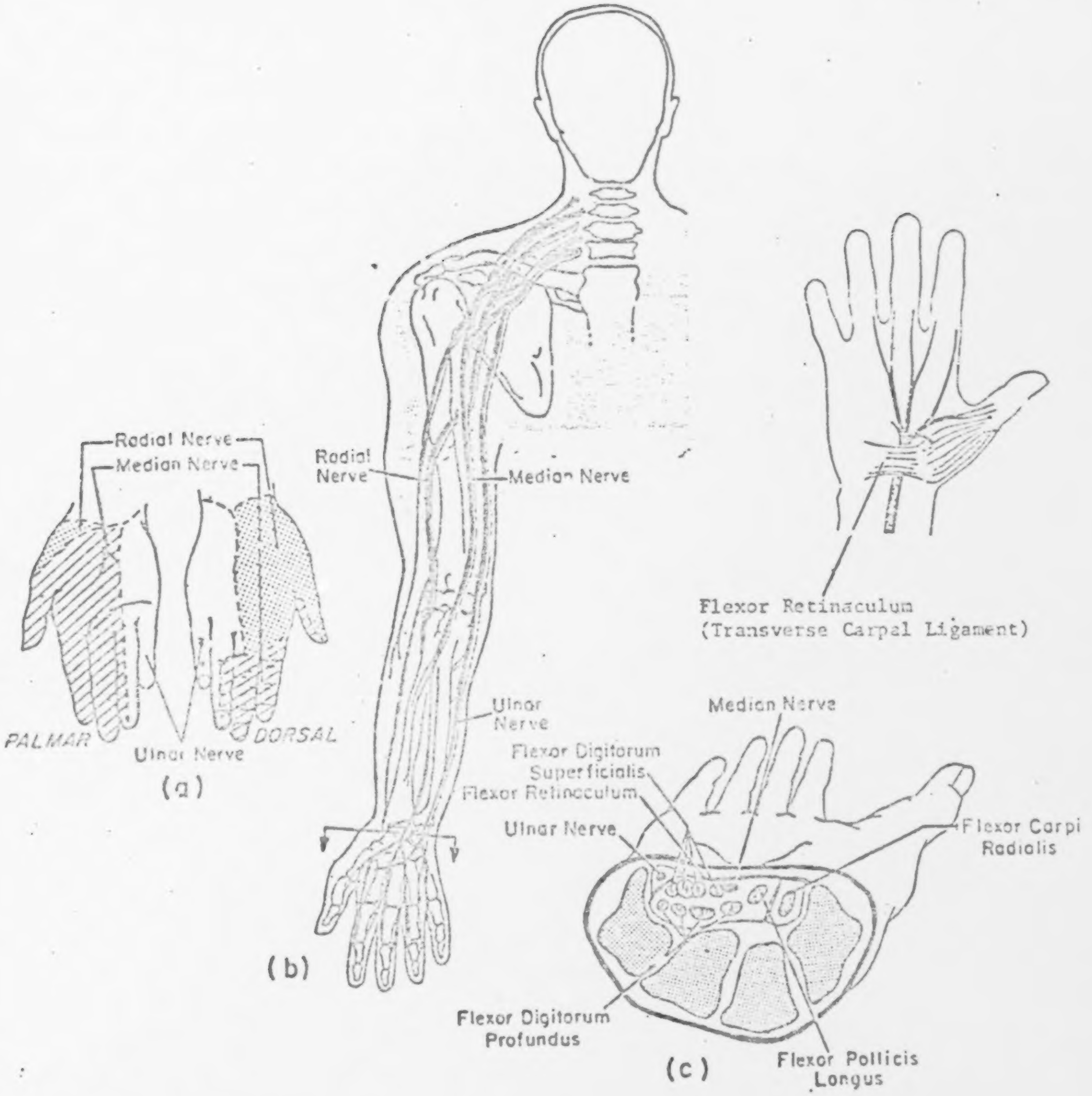

Radial Nerve
Median Nerve
PALMAR
DORSAL
Ulnar Nerve
(a)
Radial Nerve
Median Nerve
Ulnar Nerve
(b)
Flexor Retinaculum
(Transverse Carpal Ligament)
Median Nerve
Flexor Digitorum
Superficialis
Flexor Retinaculum
Ulnar Nerve
Flexor Carpi
Radialis
Flexor Digitorum
Profundus
Flexor Pollicis
Longus
(c)

FIGURE 1. The median nerve is one of three major nerves that innervate the upper extremity and provide motor, sensory and autonomic function, b. The median nerve generally provides sensory function in the first three and one half digits and over the base of the thumb, a. The median nerve passes through the carpal tunnel with the finger flexor tendons, c. (Adapted from Armstrong, T.: An Ergonomics Guite to Carpal Tunnel Syndrome. American Industrial Hygiene Association, Akron, Ohio. In press.)

IV. CLINICAL PRESENTATION OF CTS

A. Common Presenting Complaints

Unless associated with direct trauma, the onset of symptoms [illegible] CTS is usually nocturnal and insiduous. Many patients will refer the tingling to all the digits and sometimes to the whole hand. In the series of Kremer _et al._ (1953) only half of the patients were able to localize their symptoms to digits in the median territory, namely the thumb, index, middle and half the fourth finger. The pain in the hand may initially be described as episodes of tingling and numbness with gradual progression to more severe symptoms referred to as burning, aching, pricking, or tight and bursting, or as a painful numbness in the fingers and deep in the palm. There are, however, some individuals who do not complain of these symptoms, but develop progressive weakness and wasting of the thenar muscles supplied by the median nerve, with or without sensory loss in the fingers.

Many patients will have accompanying pain in the forearm which may reach the shoulder. This is usually described as a dull aching pain felt deeply in the limb, and its intensity may be related to the severity of the pain in the hand.

The usual complaint is of attacks of painful tingling in one or both hands at night, sufficient to wake the sufferer after a few hours sleep. With the pain and tingling there is a subjective feeling of uselessness in the fingers, which are sometimes described as feeling swollen. Yet, on inspection, little or no swelling is apparent. Relief may be obtained by hanging the arm out of bed or shaking or rubbing the hand, but as symptoms increase, the patients often get out of bed and walk about until eased. At this stage attacks of tingling may develop during the day, but the associated pain in the arm is much less common than at night. Objective changes in sensation and power may appear in the hand, but some patients may suffer severe attacks of pain for many years without developing abnormal neurological signs. There may be clumsiness and difficulty in performing certain tasks, such as unscrewing bott'e tops, turning a key, or crocheting.

Color changes in the fingers have been described particularly with exposure to cold, but they are not related to the attacks. Also, excessive sweating and mild degrees of edema are related to the vasomotor imbalance known to exist in CTS.

Although carpal tunnel entrapments are bilateral in more than half the cases (Cseuz et al., 1966), symptoms usually first appear and are more severe in the dominant hand, likely as a result of greater use (Phillips, 1967).

The previous description may be the more common presentation for CTS, but complaints of pain in the neck and shoulder greater than the forearm and hand has frequently been described in this disorder (Crymble, 1968). In brachial neuralgia (pain in arm from nerve injury) from any cause, there of. . is nc correlation between the site of the lesion and the distribution of the pain (Lishman & Russell, 1961).

Interesting cases referred to this author which were found to have CTS have included exclusive shoulder pain which was evaluated with an anthrogram by the referring physician; neck pain with radiation to the osciput??? resulting in a request for a migraine evaluation but relief was obtained following treatment of the underlying CTS; and pain over the left pectoral muscles with extension into the left arm, obviously very worrisome symptoms, were related to carpal tunnel syndrome in a young left-handed female who taught exercise classes and was repainting the inside of her home. Poor localization of pain and sensory loss by patients has also resulted in an evaluation for transient ischemic attacks before the diagnosis of CTS was made. Suspicion of the presence of CTS in these cases with an unusual presentation occurred when a history of exacerbation of the symptoms was noted with rest or while sleeping.

Proximal symptoms have been attributed by some to multiple sites of entrapment. However, in this author's experience, these symptoms usually abate with treatment of the carpal tunnel syndrome. Obviously in the cases of clinically apparent cervical spine disease and CTS, both must be treated in order to obtain relief (Upton and McConas, 1973).

B. Physical Examination

Sensory signs within the median nerve distribution are best sought for in the finger tips, where impairment is, as a rule, more pronounced. Occasionally in place of decreased sensation, there is an overreaction to cutaneous stimuli. A decrease in the perception of a sensory stimulus in the median innervated lateral three and a half fingers has been reported to be present in 70 percent of CTS cases (Doyle & Carroll, 1980). Isolated thenar wasting or sensory impairment in the distribution of individual digital (finger) nerves may be the presenting feature of median nerve lesions at the wrist. Flattening of the thenar (thumb) eminence was formerly a common sign of median neuropathy, but now, in view of greater awareness of CTS, marked wasting is seldom seen. A revealing sign, when present, is a mild weakness of the abductor pollicis brevis (muscle which moves thumb away from palm at right angle to palm) or of the opponens pollicis muscle (muscle which allows thumb to be moved across the palm to the 5th digit). Manual pressure over the flexor aspect of the wrist or prolonged hyperextension or hyperflexion (Phalen's sign) of this joint may reproduce sensory symptoms. A Tinel's sign, consisting of shockline pain and tingling elicited by percussion of the median nerve at the wrist, is less common a finding than often thought. One study reported the presence of Tinel's sign in 45 percent with CTS and 29 percent without the disorder (Stewart & Eisen, 1978), while another study found no statistically significant difference after examining the same problem (Glemers, 1981).

V. ANCILLARY DIAGNOSTIC TESTS

A. Nerve Conduction Studies (Electromyogram)

Although abnormalities of the electromyogram are more likely to be found in the presence of a defect on clinical examination in CTS, a significant number of patients have no abnormalities other than those detected on electrodiagnostic testing. In a series of 300 individuals with CTS, two-thirds with normal sensory perception had abnormality of conduction in testing the different fibers (Thomas et al., 1966). Eighty-five percent of the entrapped median nerves had electromyogram abnormalities (Cseuz et al., 1966) in the Mayo Clinic series. In Spinner's (1978) large collection of CTS cases, 25 percent had normal electrodiagnostic studies.

Although abnormalities of conduction in motor fibers of the median nerve are frequent and are important findings in CTS, abnormalities of sensory fibers occur with even greater frequency. Nearly 90 percent of patients in the series of Thomas et al. (1967) had abnormalities on stimulation of the afferent (sensory) fibers of the median nerve from the index finger, and in some instances, this was the only objective evidence to support the clinical diagnosis.

In their experience (Thomas et al., 1967), needle-electrode examination (needle inserted into muscle to measure its activity) was not as useful a test in CTS as were studies of nerve conduction. Of the 213 patients who underwent needle-electrode examination, 91 percent showed abnormal conduction of the nerve, but only 41 percent were found to have fibrillation potentials (seen in a muscle study when its nerve supply is diseased). Marinacci (1964) differs in his conclusions, with 96 percent of his CTS cases having abnormal needle-electrode studies.

Upton and McComas (1973), who originally described the "double crush" syndrome, found 70 percent of their entrapment cases to have electrophysiological evidence of neural lesions in the neck.

Yu et al. (1979) reviewed the electrodiagnostic records of 525 cases with carpal tunnel syndrome revealing 20 percent to be associated with other neurologic disorders, primarily cervical root involvement. This may reflect the age of the population studied since Yu describes the association of CTS and cervical root disease to be highest in the over 60 group. The present author has found this association to occur relatively infrequently.

B. Vibration Threshold

The modified Optacon is a portable electronic device that converts visual images into tactile forms to assess fingertip sensation. The test is rapid, non-invasive and simple to administer (Arezzo, 1980; Bleecker, in press).

Abnormal vibratory perception in the median innervated index finger in comparison to the ulnar innervated ipsilateral little finger has been reported as the earliest non-provocative sign of CTS. Dellon (1980) found an abnormal perception of vibratory stimuli in 72 percent of patients with a history compatible with CTS. The modified Optacon is able to measure this sensory deficit at the site of onset, the fingertips (Bleecker, in press). Preliminary studies show that the difference in the vibratory threshold between the involved II digit and the involved V digit are significantly elevated in CTS as compared to the controls. The modified Optacon is believed to stimulate the rapidly adapting mechano-receptors, the Pacinian corpuscle, since its maximum sensitivity occurs at 200-300 Hz.. Arezzo et al. (1983) have demonstrated the utility of the modified Optacon as a screening tool in the workplace by examining 257 acrylamide-exposed individuals for evidence of early toxic neuropathy.

C. Pneumatic-Tourniquet Test

In normal people, arrest of the circulation in the arm by inflation of a blood pressure cuff above the elbow is followed within one or two minutes by a faint "fluttering" or "vibration" sensation in the hand or fingers, which usually develops into a diffuse tingle uniform in quality and without the sharp pricking component characteristic of postischemic pins and needles.

When this procedure is performed in an individual with carpal tunnel syndrome, intense tingling or sensory loss restricted to the median territory occurs. The intense tingling never spreads to the little finger. The occurrence of sensory loss in all median-supplied fingers has been regarded as suggesting damage to the median nerve when it has occurred within 8 or 10

Reproduced from best available copy.

minutes of the inflation of a cuff around the arm, particularly when a further interval of several minutes has elapsed before involvement of the remaining fingers (Gilliatt, 1953).

D. Thermography

Liquid crystal thermography has only recently been applied to the study of CTS, and appears to be sensitive in detecting asymmetries in heat distribution (Gateless, 1983). Liquid crystal thermographs probably reflect vasomotor instability resulting from compromise of the sympathetic nerves which are carried in the median nerve. As a non-invasive method for diagnosing and following carpal tunnel syndrome, this may have potential, but further studies are still needed to determine whether this technique is only identifying a subpopulation of those with CTS or if these temperature changes are a common finding.

VI. PATHOPHYSIOLOGY

, In an attempt to define the pathology of the median nerves in CTS, Thomas and Fullerton (1963) were able to dissect the median nerves 3 hours after death of a patient with known CTS in the right hand. A considerable increase in the thickness of the perineurium (connective tissue around groups of axons) and the amount of endoneurial connective tissue (connective tissue around each individual axon) was apparent in the sections taken from under the transverse carpal ligament and at 1 cm above the ligament when the right was compared to the left side. Measurement of axons revealed a relative loss of large fibers on the right. Even in the digital (finger) nerves the identical pathology was seen. The mean values of fiber diameter both under the transverse carpal ligament and in the digits were compared: in both the right and left hands, the differences were all highly significant ($p<0.01$).

The relative roles of pressure deformation and ischemia in the production of compression nerve lesions (CTS) remains a controversial issue with most attributing the nerve lesion in the carpal tunnel to compression. Sunderland (1976) supported the vascular theory in which he describes the initial lesion as anoxia in the nerve caused by obstruction to venous return. This was followed by edema in the nerve and an increase in pressure within the nerve which finally results in destroyed nerve fibers secondary to impairing their blood supply. The final outcome is fibrous tissue replacement of the contents of the nerve.

Fullerton (1963) studied the effect of ischemia produced by a pneumatic cuff on conduction in motor fibers of the median nerve in patients with CTS. Decreases in action potential size was not due to changes in nerve threshold, to venous congestion, or to a fall in temperature. Susceptibility to ischemia in the carpal tunnel patients was not related to the duration of symptoms, degree of muscle wasting and weakness, or to the latency of the muscle response following wrist stimulation. It was, however, closely related to the severity of pain and paresthesia in the days preceding the test. Therefore, Fullerton proposed two mechanisms which may be responsible for the abnormalities in CTS, one being a rapidly reversible change in the nerve fibers associated with ischemia attacks which cause pain, paresthesias and transient weakness with reversible failure of nerve conduction and the other a slowly developing structural change in the fibers resulting from pressure on the nerve under the transverse carpal ligament resulting in an increase in

Reproduced from best available copy.

latency. In the majority of patients, both ischemia and direct pressure appear to contribute to the abnormality of nerve function.

VII. ETIOLOGY (CAUSE) OF CARPAL TUNNEL SYNDROME

Basically, the cause of CTS will be discussed under three categories depending upon the anatomical site of the major pathology. With the carpal canal forming a rigid compartment, decrease in the size of the canal, enlargement of the median nerve or increase in the volume of the other structures within the canal may all have one common result, namely to compress the median nerve. It must be remembered that many cases are idiopathic (cause unknown). Examples of diseases corresponding to the anatomical site of major pathology will be included.

A. Decrease of Cross Sectional Area of Carpal Canal
   1. Malaligned fracture
   2. Chronic trauma (Browne, 1975)
   3. Arthritis
      Rheumatoid arthritis -- carpal canal stenosis and teno-synovitis present (Michaelis, 1950; Barnes & Currey, 1967; Chamberlein, 1970; Herbison et al., 1973)
      Gouty arthritis (Grossman, 1961)
   4. Bone Disease, Paget's
   5. Increase in thickness of transverse carpal ligament
   6. Congenital defects (bony protrusions into the carpal canal and carpal canal stenosis (Dekel *et al.*, 1980; Gelmers, 1981)

B. Enlargement of the Median Nerve
   1. Endoneurial edema -- increase fluid in the median nerve
      diabetes
      acromegaly -- usually present in active disease (O'Duffy, 1973)
      lead neuropathy (Bleecker, in press)
      inflammation of the nerves
   2. Amyloid -- infiltration of nerve in hereditary or primary amyloid (Bastion, 1974)
   3. mucopolysacharrides (infiltration of nerve in Myxedema-hypothyroid) (Purnell, 1961)

4. Neuroma of the median nerve (McGrath, 1979)
5. Pseudoneuroma of attrition of the median nerve -- fibrous hypertrophy of nerve sheath

C. Increase Volume of Contents in the Carpal Canal

1. Tenosynovitis -- inflammation of tendon sheath
2. Tendonitis -- inflammation in the tendon
3. Granulomatous tenosynovitis -- tenosynovitis secondary to an infection (Stratton, 1981)
4. Ganglion (Doyle, 1968)
5. Lipoma
6. Calcium deposits -- gout (Grossman and Demartini, 1961)
7. Amyloid -- deposited in tendons or within the carpal tunnel in multiple myeloma (Grossman, 1961; Grokoest, 1954)
8. Aberrant artery accompanying median nerve
9. Anomalous muscles extending into or originating in the carpal tunnel
10. Hematoma -- post-traumatic
11. Fluid Retention
    Pregnancy (McCallum, 1959)
    Oral contraceptives (Sabour, 1970)
12. Increase growth of connective tissue
    Menopause and Gynecological Surgery (Bjorkquist et al., 1977)
    Acromegaly (Schiller and Kolb, 1954)

??? 13. Venous distention in the carpal tunnel 20 to A-V Fistula for hemodialysis (Delaney, 1982)

VIII. FACTORS RESPONSIBLE FOR THE DEVELOPMENT OF CTS IN THE WORKPLACE

Occupational factors responsible for the development of CTS include physical exertions with certain hand postures or against certain objects, and exposures to vibration or cold temperatures. Also, a worker who is new on the job or returning from a holiday may be more prone to this condition. In this setting the most common etiology is tenosynovitis with secondary compression of the median nerve.

A. Work Method

This includes the study of hand and wrist position and hand force by the use of cinematography and electromyography. Armstrong (1979) examined 36 females, 18 with the carpal tunnel syndrome, using the above techniques and found that those with CTS tended to use a wrist position that is deviated from the straight position more frequently and that they tended to exert greater hand force in all wrist positions.

Repeated and forceful movements of the flexor tendons back and forth through the carpal tunnel is an important factor in the development of synovitis (swelling in sheath around the tendon). Flexion and extension of the wrist causes the tendons to be displaced past and against the adjacent walls of the carpal tunnel. Contact forces between the tendons and adjacent surfaces no doubt contribute to synovitis and in turn to carpal tunnel syndrome. Brain and associates (1947) considered hyperextension of the wrist to have a more significant role in CTS since pressure inside the tunnel rose to 100 mm of water with flexing, but 300 mm of water with extension. It is evident that there is an increase of pressure (decrease of volume) within the carpal tunnel in both the acute flexed and the hyperextended positions of the wrist (Tanzer, 1959). Forceful movements and direction of movements are only two of the causes underlying the development of tenosynovitis in the worker; Luopajorvi et. al. (1979) also emphasized the speed of the movements, frequency of movements, total number of movements and incorrect posture while working as responsible factors.

Median nerve compression also can be caused by tasks that require a sustained or repeated stress over the base of the palm (Kendall, 1960). Examples of the tasks that often produce pressure on the base of the palm include the use of screwdrivers, scrapers, paint brushes, and buffers. Such tasks should be designed so that grip stresses are distributed over the muscular eminances at the base of the thumb and little finger and not in the center of the palm.

B. Vibration

Athough the mechanism is not yet understood, vibration exposure (low frequency 10-40 Hz) is a recognized risk factor for CTS (Rothfleisch, 1978). Vibration exposure may result from air or motor powered drills, drivers, saws, sanders or buffers. Cannon (1981) examined medical records at an aircraft company and found a strong association between CTS and use of vibrating tools. Traumatic Raynaud's phenomenon in workers using vibrating tools has been attributed to a peripheral nerve lesion, though the exact location has not been determined. The description of nocturnal disturbances in 13 out of 37 workers with Raynaud's phenomenon were highly suggestive of the carpal tunnel syndrome (Marshall et al., 1954) and probably reflect a subpopulation of workers with vibration white finger disease secondary to compromise of the sympathetic nerves and not a primary vascular lesion.

C. Hand Tool Design

A tool should be designed to extend and reinforce range, strength and effectiveness of the limb engaged in the performance of a given task. Injurious stress on the hands has two basic causes: excessive use against resistance and use while in an abnormal position. Repeated gripping is the most common, resulting in cramp and fatigue of the muscle. A frequent motion which is predisposing to tenosynovitis is "clothes wringing": insertion of screws, looping of wire while using pliers or manipulation of rotating switches or controls coaxially with long rods (Tichauer and Gage, 1977).

The tool handle should be designed so as to permit the wrist to be kept straight during work. A key rule is to avoid ulnar deviaton.

D. Hobbies

It must be remembered that CTS may also result from non-occupational activities such as knitting, crocheting, hooking rugs, playing a musical instrument, painting, wood working, gardening and lifting weights.

IX. CONDITIONS ASSOCIATED WITH CTS

A. Systemic Diseases or Conditions Associated with CTS

Obesity
Diabetes Mellitus
Thyroid Dysfunction
Rheumatoid arthritis
Raynaud's Phenomenon
Gouty arthritis
Pregnancy
Syphilis
Hyperlipidemia
Acromegaly
Cushing's Disease
Hysterectomy
Cirrhosis of the liver
Amyloidosis
Purpira simplex
Sarcoidosis
Lupus erythematosis
Scleroderma
Pernicious anemia
Positive family history for CTS
Pyridoxine deficiency

In the author's neurology clinic, several patients who have required the use of a walker whether for stability or weakness have developed CTS. These have included cerebrovascular accidents, cervical spondylosis, multiple scelerosis, myelopathies and dementia.

B. Conditions Associated with CTS in the Workplace

1. Nonspecific Tenosynovits -- most common (Luopajarvi et al., 1979)
2. Trigger digits -- A condition of partial obstruction in flexion or extension of a finger (Phillips, 1967)
3. DeQuervain's Disease -- tenosynovitis of extensor tendons of thumb
4. Injury to flexor tendons in fingers -- resulting in a posttraumatic tenosynovitis (Browne, 1975)
5. Dupuytren's Contracture -- contracted state of the palm and fingers

due to injury (Luck, 1959)

6. Vasomotor imbalance (Most of the sympathetic nerve supply to the hand is carried in the median nerve. (Phalen, 1966)
7. Fibromyositis -- inflammation of fibromuscular tissue
8. Age
9. Sex (3:1 - 10:1 ratio of women to men depending on series reported in the literature)
10. Dominant hand (Phillips, 1967)

C. Other Conditions Confused with CTS

1. Cervical rib compression of median nerve may result with thenar wasting as part of a costoclavicular syndrome.
2. Band compressing the brachial plexus presenting much the same as a cervical rib.
3. Cervical Spine Disease may cause median nerve compression though these symptoms are usually relieved by rest and worsened by straining or by movement of the neck.
4. Cervical-disc degeneration resulting in nerve root compression.
5. Thoracic outlet syndrome results in loss of bulk or strength in the hand other than the thenar, together with sensory finding on inner side of hand.
6. Double crush syndrome -- refers to co-occurrence of cervical root damage with CTS accounting for proximal pain in the upper extremity (Upton, 1973)
7. Ulnar nerve entrapment with a Martin-Gruber anastomosis -- an anomaly in which the ulnar and median nerves are connected in the forearm (Posner, 1973; Iyer and Fenichel, 1976)
8. Polyneuritis -- disease of many nerves often presenting with pins and needles in hands and feet

X. TREATMENT OF CARPAL TUNNEL SYNDROME

Present day treatment of CTS includes:

1. Immobilization of the wrist which consists of a close fitting anterior splint which extends from the upper part of the forearm to the metacarpophalangial joints. This is worn by the patient at night or when resting and holds the wrist immobilized in a neutral position.

2. Injection of hydrocortisone into the carpal canal. This usually provides only temporary relief of symptoms and has the added danger of injecting the median nerve accidently.

3. Surgical treatment consists of the complete division of the

transverse carpal ligament. In search of complications following carpal tunnel decompression, Das (1976) reported 85 percent of 120 hands were asymptomic while the remainder were unsatisfactory. Half of these had persisting symptoms while the remainder were iatrogenic (a result of the surgery).

4. Anti-inflammatory medication, Prednisone, 15 - 20 mg a day was very successful in the series of Lees and Liversedge (1959), however, the lasting benefit was not determined. In light of the serious side effects due to oral steroid medication, non-steroidal anti-inflammatory drugs such as Motrin or Indocin, for a short duration (3 - 4 weeks) are recommended.

5. Complete rest from work essentially has the same effect as immobilization, but is a more stringent conservative therapy.

Other methods of treatment which were employed in the past have included pads to protect the palm since Kendall (1950) regarded external pressure on the palm as an important etiologic factor.

Relief of symptoms in menopause patients was obtained with the administration of estrogens. With the large doses used, a number of the patients had abnormal uterice bleeding or toxic symptoms (Schiller and Kolb, 1954). On the other hand, Kremer et al. (1953) found estrogens to be entirely ineffective.

Diuretics, with or without fluid and salt restriction, have been used with success in a few isolated cases, especially in pregnancy (McCallum, 1959; Wood, 1959). In 35 non-pregnant patients, 29 of 35 were symptom-free or much improved after one month of treatment with chlorothiazide (Heathfield, 1961). At the end of three months, 19 of the 29 were still symptom-free, but 10 had relapsed on the treatment. Therefore, only 54 percent appeared to have a successful outcome using diuretics.

The work of Ellis and Folkers (1976, 1977, 1978) found patients with CTS to be deficient in vitamin B_6 (pyridoxine). Seventeen clinical signs and symptoms, by scores had disappeared or decreased after 6 weeks of B_6 therapy; after 11 weeks, greater clinical improvement was evident. Criteria included the use of the Preston pinch gauge for evaluation of hand performance which was improved after 11 weeks. Consideration must be given to the underlying pathophysiology, since pyridoxine deficiency is well known to cause a polyneuropathy and may be associated with a diffuse thickening and low grade edema in periarticular tissues of joints, conditions both of which may result in the carpal tunnel syndrome. The essentiality of pyridoxal phosphate to proteins, enzymes, and hormones is so extensive that Vitamin B_6 is a most important vitamin for life itself and for health. Even a low degree of tissue deficiency would soon be equated with some nature of overt clinical disease depending upon the scientific enzymatic reactions that were deficient in pyridoxal phosphate. The syndromes of human deficiencies of Vitamin B_6 have not included the carpal tunnel syndrome. Further investigation will be needed examining the role of Vitamin B_6 in the carpal tunnel syndrome in those individuals who do not present with a severe syndrome secondary of Vitamin B_6 deficiency.

Exercises and other forms of physiotherapy aimed at elevating the shoulder girdles have in the past been said to relieve the symptoms of the carpal tunnel syndrome but examination of the reports indicate that it is seldom helpful and of limited value for lasting relief (Crow, 1960).

In Crow's (1960) detailed investigation of 70 cases of CTS, 59 percent experienced complete spontaneous remission of symptoms from a few weeks to a few years. Such remissions were initiated in some cases by a period of complete rest, or a change of occupation, or a reduction in manual work, or a spell of warm weather, but in others they occurred for no discoverable reason.

Immobilization of the wrist at night induces a fairly rapid remission in about 70 percent of patients, but the long-term results are likely to be satisfactory in only about half of these. Though some have recommended immobilization only in cases of recent onset, Crow found that cases of even very long durartion are just as likely to benefit. It seems worth a trial where a lengthy period of use of night splints is acceptable to the patient.

A recent report of the management in 62 cases of CTS (van Rossum, 1980) (female 84 percent, male 16 percent) described the indications for surgery to be related to the severity of the complaints, accompanied by prolonged, or increasing prolongation of the distal motor latency time of the median nerve. In patients with less severe complaints and without thenar wasting and/or weakness, a conservative attitude was maintained in spite of prolonged motor latency. Similarly, in patients with rather severe complaints but only borderline latency values on repeated examination, conservative treatment was preferred. Of the 62 patients, 25 were treated conservatively and 37 underwent surgery. Conservative treatment consisted of either carbanazepine therapy, or the advice not to strain the affected hand, or both. Surgical therapy consisted of transection of the transverse carpal ligament. Patients were considered cured when freed of complaints, irrespective of whether or not residual paresis and/or atrophy of thenar muscle was detected at the end of the follow-up period. In the conservative group, 7 out of the 25 patients (28 percent) had a persistent CTS versus 6 of the 37 patients (16 percent) operated upon.

XI. CASES OF CARPAL TUNNEL SYNDROME STUDIED AT THE NEUROMETRIC LABORATORY AT BALTIMORE CITY HOSPITALS IN 1982

The symptomatic cases of CTS shown to have positive electrodiagnostic findings in the Neurometric Laboratory at the Baltimore City Hospital were reviewed for the year 1982. A total of 143 cases were found with 94 females and 49 males giving a female to male ratio of 2:1. The actual number in each decade is shown in Figure 1. Interestingly, both sexes had 55 percent of the total group between the ages of 40 to 60. In the remaining female patients, 21 percent were between the ages of 20 to 40 and 23 percent between the ages of 60 to 80. The males were more skewed to the younger age group, with 35 percent between the ages of 20 to 40 and only 10 percent between the ages of 60 to 80. The increased prevalence in the younger males probably reflects their occupations since the majority needed substantial use of their hands (Table II). In the female group many had occupations not commonly associated with CTS (Table III), but review of their hobbies revealed 26 percent to be involved with sewing, crocheting, needlepoint, or knitting. Hobbies in the male patients which involve considerable repetitive straining of the wrist included bowling, carpentry, mechanics and sports. As noted in the literature, symptoms extended in this group from one month to 12 years with little correlation to the severity of the disorder.

Telephone follow-up was possible in 55 females and 29 males. No therapy was given to 10 (24 percent) of the females and 6 (31 percent) of the males, with spontaneous resolution of the symptoms in 31 percent and 44 percent, respectively. Of the 23 females treated with splints, 12 (32 percent) reported complete relief with one moderate response and 9 complaining of failure. Conservative therapy with splints was successful in 4 (44 percent) males with one moderate response and 4 (44 percent) persistence of symptoms. Surgery was performed in 19 females (34 percent) with success in 14 (74 percent), moderate response in one and persistence of symptoms in 4. Eleven males (38 percent) had carpal tunnel release with success in 6 (55 percent), moderate response in one and a poor response in 4 (36 percent). One possibility to account for the poorer results in the male group is the return to work. There was a greater proportion of males working as compared to females in this CTS study group. The unusually low female to male ratio probably reflects the origin of our referrals, namely, the industrial area or Baltimore. Another consideration is the possibility of undetected cervical spine disease with root compression accounting for the persistence of symptoms.

Medical risk factors revealed an interesting difference in the prevalence of arthritis with a positive response in 41 percent of the females and 21 percent of the males, while past history of a fractured wrist was higher in the males with 17 percent versus 7 percent in the females. Presence of hypothyroidism and diabetes was higher in the female group (11 percent and 13 percent) versus the males (3 percent and 7 percent). Therefore, in this particular population, underlying medical problems may play a more significant role in the development of CTS in females while in the males the ergonomic stresses in the workplace may be more important. Knowledge of these facts allows a more rational approach in the choice of therapy in this group.

XII. MEDICAL SURVEILLANCE IN WORKERS FOR CTS

The prevention of CTS in the workplace has relied almost exclusively upon the use of ergonomic principles resulting in modification of hand tools and improvements in work station design and work practices (Armstrong _et al_., 1982; Tichaur and Gage, 1977). Thus far, no known programs focusing on the medical evaluation of CTS in the workplace exist. Many industries claim that the incidence of CTS is increasing and is one of their most disabling and costly medical problems. Modifications in hand tools may often imorove the problem. Deviation of the wrist and pinched hand positions may be prevented by use of a powered air tool, but this device generates low frequency vibration, another common cause of CTS (Cannon, 1981).

A method is needed to identify the earliest sign of CTS, to evaluate progression of the disease, and to examine the role of predisposing risk factors. Besides a questionnaire to obtain symptomatology and medical history, an evaluation of impairment in the hand by physical examination is important. The physical examination may not be very sensitive, but it allows one to evaluate the presence of wasting and weakness and rule out involvement of other nerves innervating the upper extremity. Also, a measure of nerve funrton, whether it be electrodiagnostic studies or the measurement of vibration threshold, is necessary both for monitoring the problem and identifying new cases.

Besides establishing the diagnosis and following the progression of CTS, identification of risk factors associated with CTS (see Sections VII and IX) must be obtained to help determine both the etiology and provide the appropriate therapy.

Another potential risk factor which has been given little attention is carpal canal stenosis which may be congenital or acquired as by trauma or arthritis. Dekel et al. (1980) provide the only study which has examined this problem by computerized tomography of the wrist with manual digitization. Carpal canal stenosis was associated with idiopathic carpal tunnel syndrome and there was no correlation with age. Lack of correlation between age and size of the canal suggests that stenosis of the carpal canal is inherited rather than acquired.

Obviously, the purpose of such a medical surveillance program must be prevention. When conservative therapy is employed early in the development of CTS, the natural history of progressive symptomatology with eventual median nerve impairment may be prevented. Examination of both the ergonomic and medical data will allow a more reasonable and hopefully successful approach to CTS in the workplace.

Table II: Occupations in 143 Cases with Carpal Tunnel Syndrome

Females

bookkeeper
childcare
clerk
construction
cook
crossing guard
domestic
factory worker
housewife
industrial analyst
janitor
laboratory technician
laundress
nurse
nurse's aid
payroll supervisor
sales clerk
secretary
teacher
telephone sales

Males

assembly line
burner
computer operator
construction
electrician
fisherman
groundsmen
machinist
mailman
mechanic
musician
physical therapist
printer
steel worker

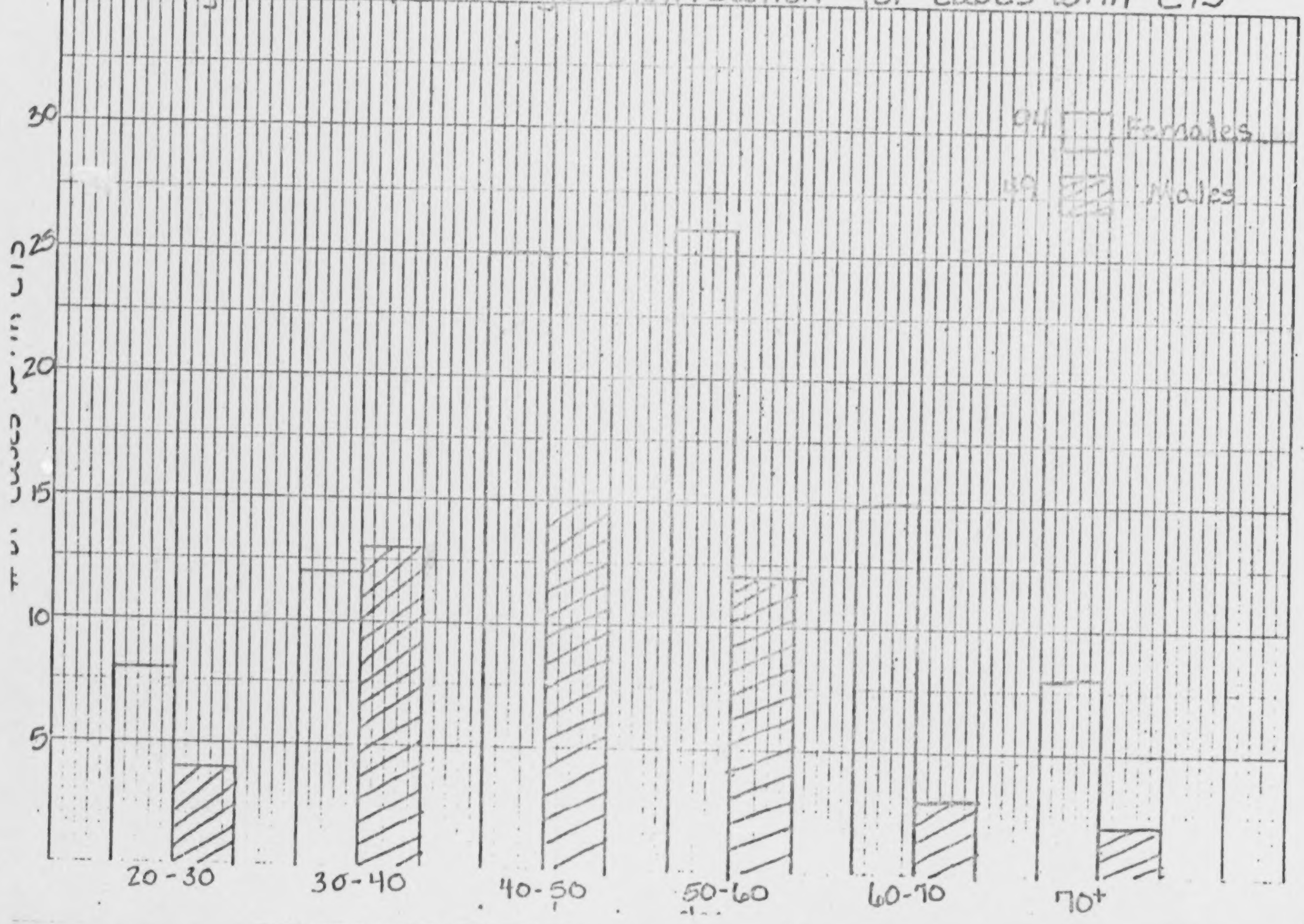
Table III: Hobbies in 143 Cases with Carpal Tunnel Syndrome

	Females	Males
Bowling	1	5
Carpentry	-	4
Clayworks/Pottery	1	-
Cooking	5	-
Crocheting	10	-
Crossword Puzzles	1	-
Fishing	-	3
Gardening	4	2
Hunting	-	1
Jewelry Work	1	-
Knitting	1	-
Mechanics	-	2
Metal Detection	-	1
Needlepoint	2	-
Painting	2	2
Sewing	11	-
Softball	2	1
Tennis	1	1

K·E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. 46 0730

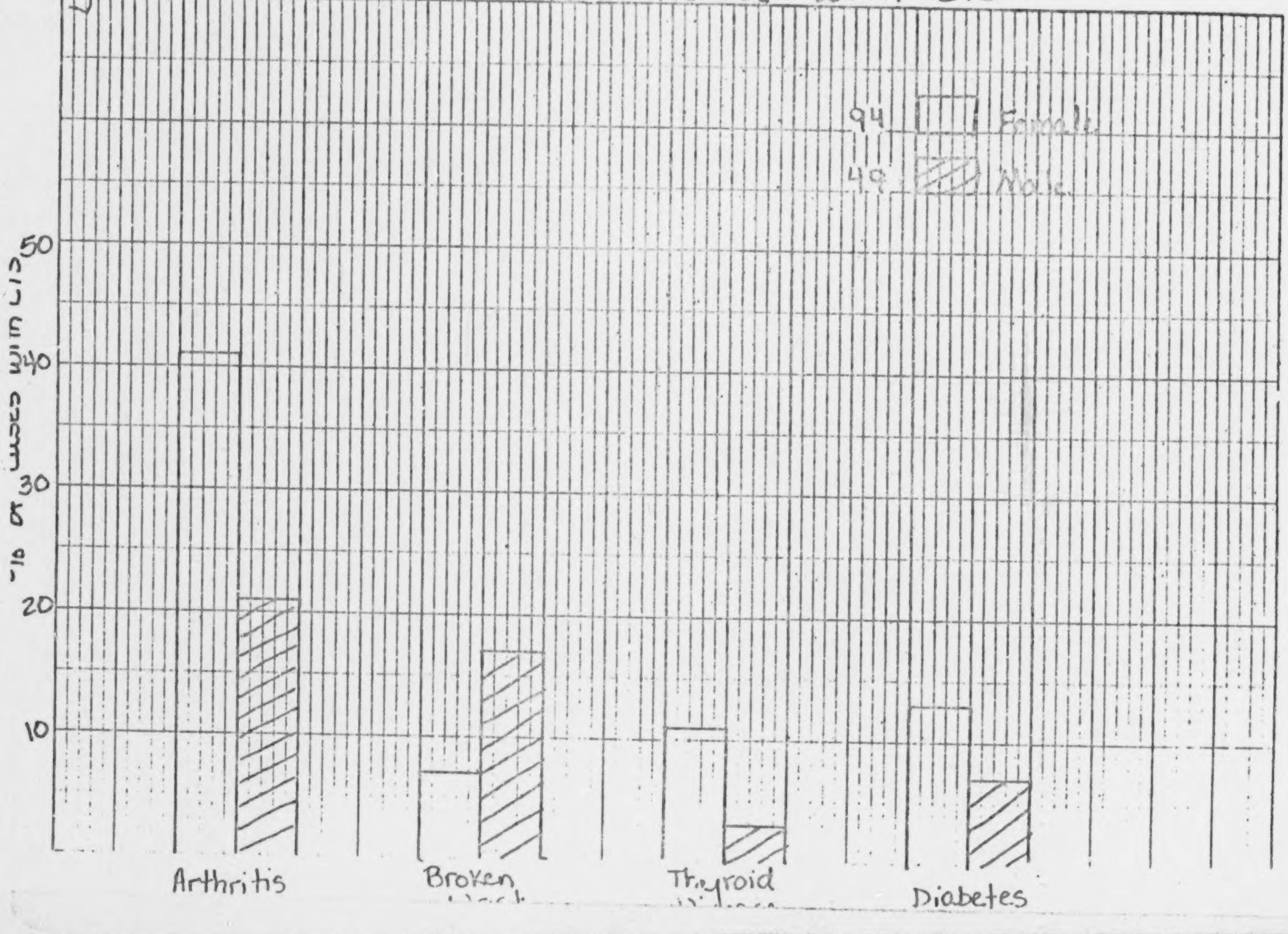
Baltimore Clinic?

Figure 1: Sex and Age Distribution for cases with CTS



K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0780

Figure 3: Risk Factors Associated with CTS



REFERENCES

Abbott, LC and Saunders, JB: Injuries of the Median Nerve in Fractures of the Lower End of the Radius. *Surg. Gynec. Obstet.*, 57:507-516 (1933).

Arezzo, JC and Schaumberg, HH: The Use of the Optacon^R as a Screening Device. *J. Occ. Med.*, 22:461-464 (1980).

Arezzo, JC; Schaumberg, HH and Petersen, CA: Rapid Screening for Peripheral Neuropathy: A Field Study With the Optacon^R. *Neurology*, 33:626-628 (1983).

Armstrong, TJ and Chaffin, DB: Carpal Tunnel Syndrome and Selected Personal Attributes. *J. Occup. Med.*, 21:481- 486 (1979).

Armstrong, TJ; Foulke, JA; Joseph, BJ and Goldstein, SA: Investigation of Cumulative Trauma Disorders in A Poultry Processing Plant. *American Industrial Hygiene Assoc. J.*, 43:103-116 (1982).

Aguayo, A: Neuropathy Due to Compression and Entrapment. In: *Peripheral Neuropathy* (PJ Dyck, PK Thomas and EH Lambert, eds.) W.B. Saunders Co., Philadelphia, pp.688-710 (1975).

Barnes, C and Currey, -: Carpal Tunnel Syndrome in Rheumatoid Arthritis. A Clinical and Electrodiagnostic Survey. *Ann. Rhem. Dis.*, 26:226 (1967).

Bastion, FO: Amyloidosis and the Carpal Tunnel Syndrome. *Am. J. Clin. Path.*, 61:711-717 (1974).

Bjorkquist, SE; Lang, AH; Punnonen, R and Rauramo, L: Carpal Tunnel Syndrome in Ovariectomized Women. *Acta Obstet. Gynecol. Scand.*, 56:127-130 (1977).

Bleecker, ML; Agnew, J; Keogh, J and Stetson, DS: Lead Neuropathy Manifested as Entrapment Syndrome in Workers. (in press).

Bleecker, ML and Birke, J: Prevalence of Carpal Tunnel Syndrome in Workers. (in preparation).

Bleecker, ML: Optacon^R -- A New Screening Device for Peripheral Neuropathies. In: *Advances in the Biosciences.* (R. Gilioli, ed.), Volume 45, Neurobehavioral Methods in Occupational Health, Pergamon Press (in press).

Brain, W; Wright, A and Wilkerson, M: Spontaneous Compression of Both Median Nerves in the Carpal Tunnel. *Lancet*, 1:277-282 (1947).

Brouwer, B: The Significance of Phylogenetic and Ontogenetic Studies for the Neuropathologist. *J. Neuro. Ment. Dis.*, 51:113-136 (1920);

Browne, EZ and Synder; CC: Carpal Tunnel Syndrome Caused by Hand Injuries. *Plastic and Reconstructive Surgery*, 56:41-43 (1975).

Bureau of Labor Statistics: Occupational Injuries and Illnesses in the United States by Industry, 1980. Washington, D.C., U.S. Government Printing Office, Bulletin 2130 (1982).

Cannon, BW and Love, JG: Tardy Median Palsy; Median Neuritis; Median Thenar Neuritis Amenable to Surgery. *Surgery*, 20:210-216 (1946).

Cannon, LJ; Bernacki, EJ and Walter, SD: Personal and Occupational Factors Associated With Carpal Tunnel Syndrome. *J. Occup. Med.*, 23:255-258 (1981).

Chamberlain, M and Corbett, M: Carpal Tunnel Syndrome in Early Rheumatoid Arthritis. *Ann. Rheum. Dis.*, 29:149 (1970).

Crow, RS: Treatment of the Carpal Tunnel Syndrome. *Brit. Med. J.*, 1:1611-1615 (1960).

Crymble, B: Brachial Neuralgia and the Carpal Tunnel Syndrome. *Brit. Med. J.*, 3:470-471 (1968).

Cseuz, KA; Thomas, JE; Lambert, EH; Love, GJ and Lipscomb, PR: Long-term Results of Operation for Carpal Tunnel Syndrome. *Mayo Clin. Proc.*, 41:232-241 (1966).

Das, SK and Brown, HG: In Search of Complications in Carpal Tunnel Decomposition. *The Hand*, 8:243-249 (1976).

Dekel, S; Papaioannou, T; Rushworth, G and Coates, R: Idiopathic Carpal Canal Syndrome Caused by Carpal Stenosis. *Brit. Med. J.*, 280:1297-1299 (1980).

Delaney, P: Dialysis Carpal Tunnel Syndrome. *Neurology*, Volume 33, Supplement 2:126 (1983).

Dellon, AL: Clinical Use of Vibratory Stimuli to Evaluate Peripheral Nerve Injury and Compression Neuropathy. *Plast. Reconstr. Surg.*, 65:466-470 (1980).

Denny-Brown, D and Brenner, C: Lesion in Peripheral Nerve Resulting From Compression by Spring Clips. *Arch. Neurol Psychiat.*, 52:1-19 (1944)

Doyle, JR and Carroll, RE: The Carpal Tunnel Syndrome. A Review of 100 Patients Treated Surgically. *California Medicine*, 108:263-267 (1968).

Dyck, PJ; Grina, LA; Lambert, EH; Calder, CS; Oviatt, K; Rehader, K; Lund, BA and Skau, K: Nitrous Oxide Neurotoxicity Studies in Man and Beast. *Anesthesiology*, 53:205-209 (1980).

Ellis, JM; Kishi, T; Azuma, J and Folkers, K: Vitamin B_6 Deficiency in Patients with a Clinical Syndrome Including the Carpal Tunnel Defect.

Biochemical and Clinical Response to Therapy with Pyridoxine. Res. Commun. Chem. Path. Pharmacol., 13:743-757 (1976).

Ellis, JM; Azuma, J; Watanabe, T; Folkers, K; Lowell, J; Hurst, GA; Ahm, CH; Sherford, F and Ulrich, RF: Survey and New Data on Treatment with Pyridoxine of Patients Having a Clinical Syndrome Including Carpal Tunnel and Other Defects. Res. Commun. Chem. Path. Pharmacol., 17:165-178 (1977).

Emmett, EA; Agnew, J; Bleecker, ML; FerRara, J; Levin, BK; Jefferys, J and Maroni, M: Health Effects of PCB Exposure of GSA Switchgear Employees. Report 80-7 to NIOSH, March, 1983.

Folkers, K; Ellis, J; Watanabe, T; Saji, S and Masashiro, K: Biochemical Evidence for a Deficiency of Vitamin B_6 in the Carpal Tunnel Syndrome Based on a Crossover Clinical Study. Proc. Nat. Acad. Sci., 75:3410-3412 (1978).

Fullerton, PM: The Effect of Ischemia on Nerve Conduction in Carpal Tunnel Syndrome. J. Neurol. Neurosurg. Psychiat., 26:385-397 (1963).

Gateless, D; Nefey, PM; Ingall, JF and Gilroy, J: The Diagnosis of Carpal Tunnel Syndrome in Pregnant Women Using Liquid Crystal Thermography. Neurology, 33:240 (1983).

Gelmers, HJ: The Significance of Tinel's Sign in the Diagnosis of Carpal Tunnel Syndrome. Acta Neurochirurgica, 49:255-258 (1979).

Gelmers, H: Primary Carpal Tunnel Stenosis as a Cause of Entrapment of the Median Nerve. Acta Neurochir., 55:317-320 (1981).

Gilliat, RW and Wilson, TG: A Pneumatic-Tourniquet Test in the Carpal Tunnel Syndrome. Lancet, 2:595-597 (1953).

Grokoest, AW and Demartini, FE: Systemic Disease and the Carpal Tunnel Syndrome. JAMA, 155:635-637 (1954).

Grossman, LA; Kaplan, HJ; Ownby, FD and Grossman, M: Carpal Tunnel Syndrome -- Initial Manifestation of Systemic Disease. JAMA, 176:259-261 (1961).

Heathfield, KW: Acroparesthesias and the Carpal Tunnel Syndrome. Lancet, 2:663-666 (1957).

Heathfield, KW and Tibbles, JA: Chlorothiazide in Treatment of Carpal Tunnel Syndrome. Brit. Med. J., 1:29-30, (1961).

Herbison, G; Teng, CS; Martin, J; and Ditunno, J: Carpal Tunnel Syndrome in Rheumatoid Arthritis. Amer. J. Phys. Med., 52:68 (1973).

Hunt, JR: The Thenar and Hypothenar Types of Neural Atrophy of the Hand. Amer. J. Med. Sci., 141:224 (1911).

Hymovich, L and M Lindholm: Hand, Wrist, and Forearm Injuries: The Results of Repetitive Motions. J. Occup. Med., 8(11):575-577 (1966).

Iyer, V and Fenichel, GM: Normal Median Nerve Proximal Latency in Carpal Tunnel Syndrome: A Clue to Coexisting Martin-Gruber Anastomosis. J. Neurol. Neurosurg. Psychiat., 39:449 (1976).

Kendall, D: Etiology, Diagnosis and Treatment of Paresthesia in the Hand. Br. Med. J., 2:1633-1640 (1960).

Kremer, M; Gilliatt, RW; Golding, JSR and Wilson, TG: Acroparesthesia in the Carpal Tunnel Syndrome. Lancet, 2:590-595 (1953).

Lees, F and Liversedge, LA: Prednisone in the Relief of Acroparesthesias. Lancet, 2:1120-1122 (1959).

Lishman, WA and Luck, V: Dupuytren's Contracture. Journal of Bone and Joint Surgery, 41A:635 (1959).

Luopajarvi, T; Kuorinka, I; Virolainen, M and Holmberg, M: Prevalence of Tenosynovitis and Other Injuries of the Upper Extremities in Repetitive Work. Scandinavian J. Work Environment Health, Volume 5, Supplement 3 (1979).

Marie, P and Foix, C: Atrophie Isole de l'Eminence Thenar d'Origine Neuritique: Role du Ligament Annulaire Anterieur du Carpe dans la Pathogenie de la Lesion. Rev. Neurol., (Paris) 26:647-649 (1913).

Marie, P and Marinesco, G: Sur l'Anatomie Pathologique de l'Acromegalie. Arch. de Med. Exper et d'Anat. Path., 1 Serie, 3:539 (1891).

Marshall, J; Poole, EW and Reynard, WA: Raynaud's Phenomenon Due to Vibrating Tools -- Neurological Observations. Lancet, 1:1151-1156 (1954).

Marinacci, AA: Comparative Value of Measurement of Nerve Conduction Velocity and Electromyography in the Diagnosis of Carpal Tunnel Syndrome. Arch. Phys. Med., 45:548-554 (1964).

[illegible]llum, M: Acroparesthesias in Pregnancy. Brit. Med. J., 2:1095 (1959).

McGrath, MH and Polayes, IM: Post-traumatic Median Nerve Neuroma. A Cause of Carpal Tunnel Syndrome. Annals of Plastic Surgery, 3:227-230 (1979).

Michaelis, LS: Stenosis of Carpal Tunnel Compression of Median Nerve and Flexor Sheaths, Combined with Rheumatoid Arthritis Elsewhere. Proc. Royal Soc. Med., 43:414-417 (1950).

Moersch, FP: Median Thenar Neuritis. Proc. Mayo Clinic, 13:220 (1938).

National Institutes of Occupational Safety and Health (NIOSH): National Occupational Hazard Survey, 1972 - 1974, Cincinnati. NIOSH (DHEW, NIOSH Publication No. 78-114) (1977).

Occupational Health and Safety News, (the editors), August, 1981.

O'Duffy, JD; Randall, RV and MacCarthy, CS: Median Neuropathy (Carpal Tunnel Syndrome) in Acromegaly -- A Sign of Endocrine Overactivity. *Annals of Internal Medicine*, 78:379-383 (1973).

Paget, J: *Lectures on Surgical Pathology*. 3rd Edition, Lindsay and Blakiston, Philadelphia, p. 50 (1865).

Phalen, G: The Carpal Tunnel Syndrome. *J. Bone Joint Surg.*, 4[illegible]:211-228 (1966).

Phillips, RS: Carpal Tunnel Syndrome as a Manifestation of Systemic Disease. *Ann. Rheum. Dis.*, 26:59-63 (1967).

Posner, DM: Ehlers-Danlos Syndrome Coexisting With A Martin-Gruber Anastomosis. A Case Report. *Ohio State Med. J.*, 69:[illegible]33 (1973).

Purnell, DC; Daly, DD and Lipscomb, PR: Carpal Tunnel Syndrome Associated With Myxedema. *Arch. Int. Med.*, 108:751-756 (1961).

Ramazzini: De Morbis Artificam Diabriba (1717).

Robbins, H: Anatomical Study of the Median Nerve in the Carpal Tunnel and the Etiologies of Carpal Tunnel Syndrome. *J. Bone Joint Surgery*, 45A:9[illegible]4-964 (1964).

Rothfleisch, S and Sherman, D: Carpal Tunnel Syndrome: Biochemical Aspects of Occupational Occurrence and Implcations Regarding Surgical Management. *Orthop. Rev.*, 7:107-109 (1973).

Sabour, MS and Fadel, HE: The Carpal Tunnel Syndrome -- A New Complication Ascribed to the "Pill". *Am. J. Obstet. Gynecol.*, 107:1265-1267 (1970).

Schiller, F and Kolb, FO: Carpal Tunnel Syndrome in Acromegaly. *Neurology*, 4:271-28[illegible] (1954).

Shapiro, IM; Cornblath, DR; Summer, AJ; Uzzell, B; Spitz, KS; Ship, I and Bloch, P. Neurophysiological and Neuropsychological Function in Mercury-Exposed Dentists. *Lancet*, 1:1147-1150 (1982).

Spinner, M: *Injuries to the Major Branches of Peripheral Nerves of the Forearm.* W.B. Saunders Co., Philadelphia, pp. 198-203 (1978).

Stewart, JD and Eisen, A: Tinel's Sign and the Carpal Tunnel Syndrome. *Brit. Med. J.*, 2:1125-1126 (1978).

Stratton, CW; Lichtenstein, KA; Lowenstein, SR; Phelps, DA and Reller, LB: Granulomatous Tenosynovitis and Carpal Tunnel Syndrome Caused by Sporothrix Schenkii. *Am. J. Med.*, 71:161-164 (1981).

Sunderland, S: The Nerve Lesion in the Carpal Tunnel Syndrome. *J. Neurol. Neurosurg. Psychiat.*, 39:615-626 (1976).

Tanzer, RC: The Carpal Tunnel Syndrome. A Clinical and Anatomical Study. *J. Bone Joint Surgery*, 41A:626-634 (1959).

Thomas, PK and Fullerton, PM: Nerve Fiber Size in the Carpal Tunnel Syndrome. *J. Neurol. Neurosurg. Psychiat.*, 26:520-527 (1963).

Thomas, JE; Lambert, EH and Csuez, KA: Electrodiagnostic Aspects of the Carpal Tunnel Syndrome. *Arch. Neurol.*, 16:635- 641 (1967).

Tichauer, ER and Gage, H: Ergonomic Principles Basic to Hand Tool Design. *Am. Ind. Hyg. Assoc. J.*, 38:622-634 (1977).

Upton, AR and McConas: The Double Crush in Nerve-Entrapment Syndromes. *Lancet*, 2:359-362 (1973).

van Rossum, J; Kompkuisen, HA and Wintzen, AR: Management in the Carpal Tunnel Syndrome. *Clin. Neurol. Neurosurg.*, 82:169-176 (1980).

Wartenburg, R and Wehrle, J: Chronic Wrist Injuries Associated with Repetitive Hand Motions in Industry. Occupational Health and Safety Technical Report. Department of Industrial and Operations Engineering. The University of Michigan, Ann Arbor, Michigan (1976).

Woltman, HW: Neuritis Associated With Acromegaly. *Arch. Neurol. Psychiat.*, 45:680 (1941).

Wood, EC: Acroparesthesia in Pregnancy. *Brit. Med. J.*, 2:1254 (1959).

Yer, J; Bendler, EM and Mentari, A: Neurological Disorders Associated With Carpal Tunnel Syndrome. *Electromyogr. Clin. Neurophysiol.*, 19:27-32 (1979).

Zachary, RB: Thenar Palsy Due to Compression of the Median Nerve in the Carpal Tunnel. *Surg. Gynec. Obstet.*, 81:213 (1945).

The research underlying this preliminary report was supported by Office of Technology Assessment Contract #233-7040.0. Any opinions, findings, conclusions or recommendations contained herein are those of the authors and do not necessarily reflect the views of the Center for Policy Alternatives, The Center for Technology, Environment, and Development, Massachusetts Institute of Technology, Clark University, or Office of Technology Assessment.

IMPLEMENTATION OF THE OCCUPATIONAL LEAD EXPOSURE STANDARD

CPA/83-20 November 1983

Authors: Robert Goble, Research Associate Professor of Physics, Center for Technology, Environment, and Development, Clark University

Dale Hattis, Ph.D., Principal Research Associate, Center for Policy Alternatives, M.I.T.

Mary Ballew, Research Specialist, Center for Policy Alternatives, M.I.T.

Deborah Thurston, Graduate Research Fellow, Center for Policy Alternatives, M.I.T.

TABLE OF CONTENTS

1. INTRODUCTION/EXECUTIVE SUMMARY 1-1

- 1.1 Summary 1-1
- 1.2 Nature and Goals of the Study 1-4
- 1.3 Survey of Controversial Issues 1-5
  - 1.3.1 Types of Exposure to Lead and Classification of Control Measures 1-5
  - 1.3.2 Technical Issues 1-11
  - 1.3.3 Policy Issues 1-12
  - 1.3.4 Industrial Philosophy, Social, and Ethical Issues 1-14
- 1.4 Summary of Conclusions and Recommendations 1-15
  - 1.4.1 Implementation of the Lead Standard to Date 1-15
  - 1.4.2 Prospects for Future Improvement 1-17
  - 1.4.3 Recommendations for Control of Lead Hazards 1-18
  - 1.4.4 Implications for the Regulation of Other Substances 1-20
- 1.5 Structure of the Report 1-20

References for Section 1 1-21

2. HISTORY AND BACKGROUND: OCCUPATIONAL LEAD EXPOSURE, EFFECTS, AND REGULATION 2-1

- 2.1 Introduction 2-1
- 2.2 Health Effects of Lead 2-4
- 2.3 The Dynamics of Lead Absorption, Storage, and Excretion 2-9
- 2.4 Structure and Economic Condition of Lead-Producing and Lead-Consuming Industries 2-18
- 2.5 History of the Regulation 2-25
  - 2.5.1 Actions before Promulgation of the Standard 2-25
  - 2.5.2 Provisions of the Occupational Lead Standard 2-27
  - 2.5.3 Recent Litigation Concerning the Lead Standard 2-29
- 2.6 Changes in Environmental Exposure to Lead 2-33

References for Section 2 2-36

TABLE OF CONTENTS (continued)

3. ANALYSIS OF INFORMATION SUBMITTED TO THE OSHA HEARING RECORD, THE CHARLES RIVER REPORT, AND CASE STUDY FIRMS 3-1

3.1 Overview of Information and Conclusions 3-1
3.2 Recent Changes in Air Lead Levels 3-3
3.3 Recent Changes in Blood Lead Levels 3-10
3.4 Interpretation of Blood Lead Level Changes in Terms of Air Lead Levels, General Population Lead Exposure Changes, and Other Control Measures 3-16
3.5 Operation of the Medical Removal Protection System 3-28
3.6 Technology and Economics of Controlling Occupational Lead Exposure 3-49

3.6.1 Recent Investments in Control 3-49
3.6.2 Current Distribution of Exposure by Plant Area 3-50
3.6.3 The Potential and Cost of Future Engineering Controls, Including New Technology 3-55
3.6.4 Discussion of Overall Costs in the Light of the Economic Condition of the Industries 3-66

References for Section 3 3-76

Appendix A Employee Profile and Exposure Data

Appendix B New Direct Smelting Technology as Part of an Overall Control Program for Worker Lead Exposures in the Primary Lead Smelting Industry -- Engineering Considerations, Costs, and Economic Feasibiity

Appendix C Dynamics of the MRP Program in Individual Industries

LIST OF TABLES AND FIGURES

FIGURE 1.1 Pathways for Occupational Exposure to Lead 1-6

FIGURE 1.2 Types of Control for Occupational Exposure to Lead 1-7

FIGURE 2.1 Long Term Rise of Blood Lead Levels 2-12

FIGURE 2.2 Equilibrium Lead Storage and Flows for an Individual Exposed for Several Decades to Lead in Air at a Concentration of 50 ug/m^3 at Work 2-13

FIGURE 2.3 Best Point Estimate of Ultimate Equilibrium Benefits of Reducing Air-Lead Exposures Under Different Blood-lead level Variability Assumptions 2-17

FIGURE 2.4 Flow of Lead in the United States (1973) 2-20

FIGURE 2.5 Lead Used in Gasoline Production and Average NHANES II Blood Lead Levels 2-34

FIGURE 3.1 Distribution of Removal Times 3-34

TABLE 1.1 Categories of Control Measures 1-10

TABLE 2.1 Summary of EPA and OSHA Judgements on Lead Health Effects 2-7

TABLE 2.2 Air Lead Exposures in Selected Industries Before the New OSHA Lead Standard 2-15

TABLE 2.3 Blood Lead Levels Among Exposed Workers in Selected Industries Before the New OSHA Lead Standard 2-16

TABLE 2.4 U.S. Primary Refined Lead Production vs. Secondary Production 2-19

TABLE 2.5 Changes in Use Patterns of Lead Between 1976 and 1981 2-21

TABLE 2.6 Real (1982 Dollar) Prices, Production and Estimated Gross Revenue from Primary U.S. Lead Production 2-23

TABLE 2.7 Implementation Schedule for Medical Removal Protection 2-27

TABLE 3.1 Recent (1981-2) Distributions of Air Lead Levels 3-4

TABLE 3.2 Air Lead Exposures, Before and After Promulgation of the OSHA Lead Standard 3-5

TABLE 3.3 Approximate Average Air Exposure Level/ Approximate % Reduction 3-7

TABLE 3.4 Recent (1981-2) Distributions of Blood Lead Levels 3-11

LIST OF TABLES AND FIGURES (continued)

TABLE 3.5 Blood-Lead Levels of Exposed Workers Before and After Promulgation of the OSHA Lead Standards and 1978 Projections 3-12

TABLE 3.6 1978 Projections of the Fall in Blood Lead Levels After Promulgation of the OSHA Lead Standard 3-14

TABLE 3.7 Approximate Average Blood Lead Levels 3-17

TABLE 3.8 Reductions in Air Lead Levels and Blood Lead Levels 3-21

TABLE 3.9 Projections of the Fall in Blood Lead Levels 3-24

TABLE 3.10 Effective Projection Factors for Respirator Use in the Three Industries 3-26

TABLE 3.11 Summary of Medical Removal Program Transfers by Industry 3-30

TABLE 3.12 Medical Removal Times as a Function of Industry and Removal Level 3-33

TABLE 3.13 Nine Primary Smelter Employees on MRP 460 Days or More Removals Begun 1979-80 3-35

TABLE 3.14 Summary of Workforce Dynamics in the Major Lead Industries, by Industry, 1977-1981 3-38

TABLE 3.15 Total Monitoring and Administrative Costs of Compliance with the Existing OSHA Lead Standard 3-46

TABLE 3.16 Exposures in Primary Lead Smelter No. 1 by Plant Area 3-51

TABLE 3.17 Exposures in Primary Smelter No. 2 by Plant Area 3-52

TABLE 3.18 Exposures in Secondary Smelter No. 1 3-53

TABLE 3.19 Exposures in Secondary Smelter No. 2 3-54

TABLE 3.20 Secondary Lead Smelters -- Comparison of Costs and Air Lead Exposure Reduction 3-59

TABLE 3.21 Primary Smelters -- Comparison of Costs and Air Lead Exposure Reduction 3-60

TABLE 3.22 Summary of Overall Costs of Lead Control -- Annualized Real Costs Before Taxes 3-67

TABLE 3.23 Summary of Overall Costs of Lead Control -- Annualized Costs Per Lead-Exposed Worker 3-69

TABLE 3.24 Summary of Overall Costs of Lead Control -- Annualized Costs Per Pound of Capacity to Produce of Consume Lead 3-70

1. INTRODUCTION/EXECUTIVE SUMMARY

1.1 Summary

In the controversy that surrounds the passage of regulatory legislation and continues during rule making by an implementing agency, it is often diffficult to sort out the claims of contending parties about the effects, benefits, and costs of alternative control actions. With the hindsight of five years of experience in the implementation of the OSHA lead standard, this report compares the actual impacts of the regulation with those anticipated at the time of promulgation.

Lead is one of less than two dozen substances that have been the subjects of new rulemaking under section 6(b) of the OSHAct. It is one of two (along with cotton dust) for which the major health concern is not cancer and for which a final rule has been promulgated and sustained in judicial review.[1] The standard, like other standards for exposure to hazardous materials, sets limits on ambient concentrations for lead in air, contains provisions for environmental monitoring, establishes requirements for engineering controls and work practices, and requires that information on lead be provided to each worker.

Two features of the standard are particularly noteworthy. One is the use of biological monitoring as a backup for environmental monitoring: employers are required to provide a regular program for measuring employee blood lead levels and to temporarily remove from exposure workers whose blood lead levels exceed certain limits. To secure worker cooperation with this back-up program, employers are required to maintain the workers' usual rate of pay and seniority benefits, even if removal means a transfer to a lower rated job or a layoff. The second feature is that the standard is explicitly technology forcing: the assessment of feasibility of the engineering control requirements assumed relatively long implementation times (5-10 years) for certain industries and assumed that new process technology would become available over that time.

The lead standard was first promulgated in 1978. Its implementation has been delayed significantly by legal challenges to the standard itself and by temporary variances granted to the most heavily affected industries from the requirements of various sections of the standard. It is not possible at this point to make a final assessment of the effects of the standard, particularly in view of the long times assumed for installation of engineering controls. An evaluation to date, however, is appropriate for two closely related reasons. One is that the current administration is considering major changes in the regulation;[2] the second is that we are now approaching the time when industry must decide whether to invest in new process technology and/or new traditional industrial hygiene engineering control measures to meet the requirements of the standard.

Our major findings are:

o Both air lead and blood lead levels have come down significantly since the promulgation of the lead standard. In the most affected industries (primary smelting, secondary smelting and batteries) the numbers of workers over 60 ug/100g at any one time have been reduced between three and ten fold. The numbers of workers over 40 ug/100g in the three industries has been reduced by about a third. Finally, whereas before the standard there used to be an appreciable number (a few percent) of workers over 80 at any one time, such blood lead levels are now practically unknown.

o Particularly in view of the substantial reductions in the numbers of workers over 60 and over 80 ug/100g, it is likely that there have been major corresponding reductions in adverse health effects.

o In none of the three industries is there yet compliance with the long term mandated air lead level of 50 ug/m^3 through engineering controls, work practices and administrative controls. In primary and secondary smelting compliance with the old standard of 200 ug/m^3 has not yet been achieved. There is evidence that most plants are not in compliance with the current requirement to achieve exposure levels equivalent to an air exposure of 50 ug/m^3 through the use of respirators and other measures; about a further halving of effective exposure levels would be needed to achieve this goal.

o The reductions in blood lead levels have been roughly consistent with OSHA's predictions for the first three years of effective compliance with the standard.

o 30-50% of the observed reduction in average worker blood lead levels may have resulted from a reduction in environmental exposure due to controls on the use of lead in gasoline. This effect was not anticipated in OSHA's predictions prior to the promulgation of the standard. However the major reduction in the number of workers at particularly high blood lead levels (over 60 ug/100g) is more largely due to the operation of the OSHA lead standard.

o There are opportunities for substantial further control of lead exposures. These measures are not inexpensive (overall, annualized costs amount to about $5,000-10,000/worker according to the Charles River Report for a selected set of technological options), although there are appreciable opportunities for comparatively low cost investment in isolation-type controls. These costs would be incurred at a time when the lead industries are undergoing severe economic hardships.

o In many cases new process technology offers the prospect of better control of occupational exposures coupled with increased productivity; however, there are substantial additional risks associated with such investments which will impede their adoption in the absence of external incentives.

o The data we have analyzed so far tentatively suggest that the most effective measures for further reducing occupationally absorbed lead are measures which reduce air lead levels. We therefore recommend that, as provided in the current standard, where air exposures are above a relatively stringent PEL (preferably the current 50 ug/m^3), all "feasible" engineering, work practice, and administrative measures should be utilized to reduce exposures.

o We believe that there should be a deliberate societal consensus-building process for arriving at what is "feasible". There is a societal interest (1) in occupational and environmental health as a matter of the general welfare and fairness, (2) in maintaining U.S. technical capability and comparative advantage in lead production technology, and (3) in maintaining access to substantial lead production within the country for possible national security needs. In view of these general societal interests, it may be reasonable for there to be some governmental underwriting (such as loan guarantees) of the risks of developing and applying new lead production technology. For those establishments planning to invest in substantial new technology, some short-run regulatory relief might be in order with respect to controls on existing equipment. We suggest that these issues are best addressed in an explicit consensus-building process that would bring together all of the interests concerned--bringing authorized representatives of management and labor from the industries concerned together with EPA, OSHA, and other governmental entities as needed to work out a definitive long term agreement.

A more extended summary of our conclusions can be found in Section 1.4 below.

1.2 Nature and Goals of the Study

Information for this study has been drawn from three sources:

1) Published reviews of occupational lead exposure and/or effects.

2) The public record that has been generated in the promulgation of the OSHA lead standard and the subsequent judicial review, requests by individual firms for variances, petitions for industry wide relief from some of the provisions, etc.. Of this material, the single most helpful document is a major recent study of costs and benefits of future lead control measures done by Charles River Associates[3]

3) interviews with plant managers and industrial hygenists, OSHA officials, and labor leaders.

The goals of the project were:

o to survey and evaluate the implementation of the occupational lead standard to date

o to draw conclusions about which control measures appear to be effective in reducing worker exposure to lead and which provisions of the occupational lead standard have been most influential in the implementation of effective controls, and

o to draw lessons from the experience with lead that can be applied to the control of exposure to other hazardous materials.

1.3 Survey of Controversial Issues

1.3.1 Types of Exposure to Lead and Classification of Control Measures

In order to understand the numerous controversies that the lead regulation has generated, it is important to know something about the processes which give rise to absorption of lead by workers, to know what the possibilities for controlling absorption are, and to understand what information is provided by air lead and blood lead measurements. Figure 1.1 is a simple representation of the sequence of events from release of lead by an industrial process to its absorption by a worker with possible medical consequences. There are two important pathways for absorption--(1) inhalation of lead dust or fumes, and (2) ingestion of lead dust. The structure of the causal chain suggests one possible classification of possible control measures--illustrated in Figure 1.2. Representative control measures are displayed as possible means of blocking the various stages of the sequence. Thus control measures which reduce emissions at the source--hoods or lower emission processes--are distinguished from measures which distance or remove the worker from areas with relatively high ambient lead levels--the provision of positive pressure lunch areas or control rooms with filtered air. These, in turn, are distinguished from measures which do not affect ambient levels but which reduce worker intake such as the use of respirators and a variety of hygenic practices (e.g. showers). A final group of control measures are those which treat the already exposed worker--monitoring of blood lead and

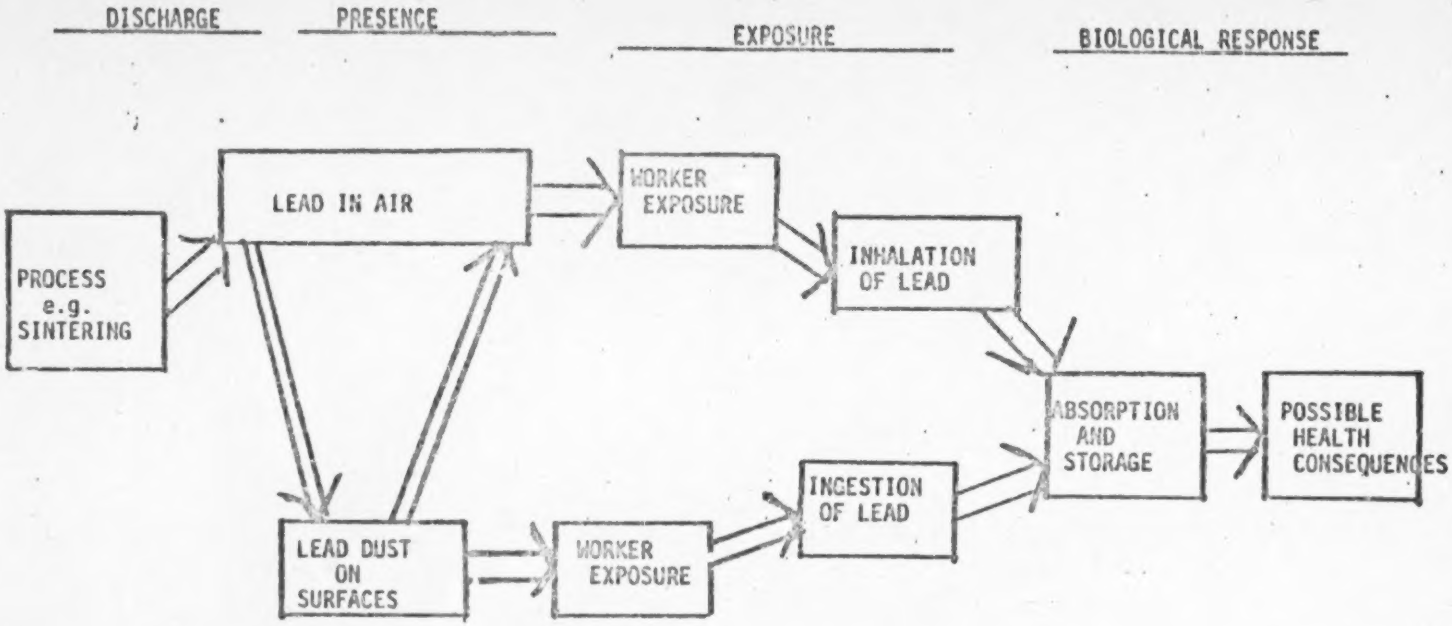

DISCHARGE
PRESENCE
EXPOSURE
BIOLOGICAL RESPONSE
PROCESS e.g. SINTERING
LEAD IN AIR
LEAD DUST ON SURFACES
WORKER EXPOSURE
INHALATION OF LEAD
WORKER EXPOSURE
INGESTION OF LEAD
ABSORPTION AND STORAGE
POSSIBLE HEALTH CONSEQUENCES

Figure 1.1
Pathways for Occupational Exposure to Lead

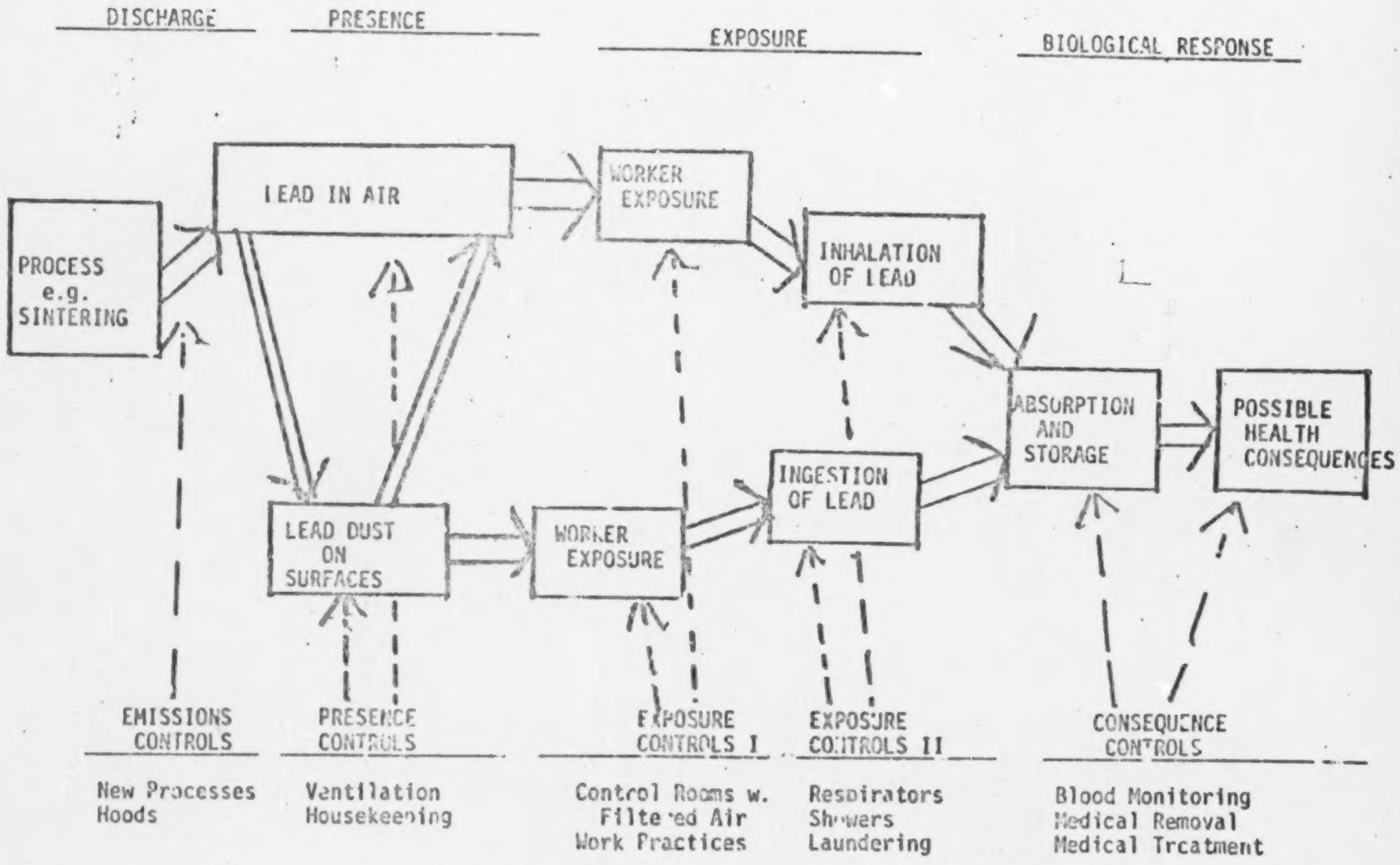

DISCHARGE
PRESENCE
EXPOSURE
BIOLOGICAL RESPONSE
PROCESS e.g. SINTERING
LEAD IN AIR
LEAD DUST ON SURFACES
WORKER EXPOSURE
WORKER EXPOSURE
INHALATION OF LEAD
INGESTION OF LEAD
ABSORPTION AND STORAGE
POSSIBLE HEALTH CONSEQUENCES
EMISSIONS CONTROLS
PRESENCE CONTROLS
EXPOSURE CONTROLS I
EXPOSURE CONTROLS II
CONSEQUENCE CONTROLS
New Processes
Hoods
Ventilation
Housekeeping
Control Rooms w. Filtered Air
Work Practices
Respirators
Showers
Laundering
Blood Monitoring
Medical Removal
Medical Treatment

Figure 1.2

Types of Control for Occupational Exposure to Lead removal from future exposure, and medical treatment, if needed. (Some would not consider medical treatment a "preventive" control at all, but it clearly can be important in limiting future health damage.) Finally, it should be noted that removal of a worker from exposure does not reduce the aggregate exposure of the worker population as a whole; it redistributes exposure among workers (in general, another worker will fill the high exposure job vacated by the removed worker).

It is important to draw these distinctions in the mechanisms of control because (1) they involve the worker to various degrees in sharing the burden of control and (2) there are likely to be significant differences in the permanence, enforceability, and costs of different kinds of controls. First, as one proceeds to the right in Figure 1.2, there is clearly a systematic tendency for greater participation of the worker in the control process. It is not very intrusive at all to reduce the air level, it involves some appreciable effort for the worker to wear a respirator, and it is a still greater potential disruption for the worker to be transferred out of his/her usual job or laid off. Second, control measures toward the left portion of Figure 1.2 tend to take the form of capital equipment, such as a new ventilation system, changes in process technology, and the like. They are likely to keep functioning whether an OSHA inspector is on premesis or not. There is relatively more chance that personnel protective equipment use and housekeeping measures can be quickly and temporarily modified for purposes of an OSHA inspection. Capital equipment controls tend to be costly, particularly in the short run; however, increases in productivity may partially offset these costs in some cases.

The distinctions in the worker involvement and permanence of different control measures have implications for the desirability of different kinds of measurements as a tool for defining and monitoring compliance with health standards. Two kinds of measurements are prescribed by OSHA standards:

- Measurement of the ambient air lead level in the air immediately around the worker. This procedure is to provide a worker with a portable air sampler which collects air while the worker is performing his/her duties. Thus a worker who spends significant periods of time in a control area with filtered air will have lowered measured air exposures, while his/her use or nonuse of a respirator will have no effect on the value measured.

- Measurement of the blood lead level for each worker. Blood lead is a direct measure of lead that has been taken in by the body over some previous period; as such it is a more complete measure of total intake than air lead since blood lead includes the effects of ingestion (and of controls such as respirator use), and it should measure better the lead that is available to do physiological harm. Unfortunately there are serious limitations in the interpretation of blood lead measurements: blood levels depend most on the average recent absorption of lead over a few weeks, but they also depend on characteristics of the individual worker, and on the amount of long term exposure he/she has had; similarly, the correlation with health effects is quite crude and depends on individual sensitivity and on the nature of the exposure over time.

The distinction between interventions at different points in the lead exposure sequence which affect differently air and blood lead measurements, and the economic distinction between measures which have a high capital cost and measures whose expense is primarily an operating one, provide the basis for our final classification of control measures. This classification is summarized in Table 1.1

Item E in Table 1.1 is not, of course, a control measure. It is placed in the table because total exposure as measured by blood lead levels includes exposure from environmental sources. As we will discuss later, there is good evidence that this exposure has appreciably decreased in the last few years.

Categories of Control Measures

A. Measures that affect air lead levels in the plant

- A-1 Major changes in production processes (e.g more continuous and automated lines for producing batteries, a direct smelting process)
- A-2 Major add-on control equipment (e.g., new ventilation system)
- A-3 Mainly operating practice change (e.g. better housekeeping, that might be facilitated by some capital--new floor allows better cleaning, but the major cost is still a daily hosing down of the new floor)
- A-4 Changes in production levels (e.g. more or less use of lead-emitting equipment)

B. Measures that do not affect ambient air levels in the plant but which limit worker time spent in plant areas with high ambient air lead levels.

- B-1 Isolation areas such as control areas with filtered air supply
- B-2 Changes in work practices which limit time spent in high concentration areas.

C. Measures that affect total worker lead absorption but do not affect air levels

- C-1 Respirators
- C-2 Showers, change of clothes before going home, etc.
- C-3 Business cycle factors; layoffs, overtime (aside from effect of different production levels included in A-4)

D. Measures that mainly affect the distribution of total exposures among individual workers but do not affect total lead intake for the workforce as a whole

- D-1 Monitoring of worker blood lead levels and removal from high exposure areas when a trigger level is reached--the medical removal provision (MRP)
- D-2 Other workforce management practices (e.g. rotation of workers, firing of highly exposed workers)

E. External effects on total exposure to lead: i.e. changes in environmental levels of lead.

1.3.2 Technical Issues

Although the general picture of lead flow, Figure 1.1, and the classification of controls, Figure 1.2 and Table 1.1, are not controversial, there is an intense debate on the detailed operation of the processes summarized in those pictures. We can identify four families of technical arguments based on fundamental uncertainties:

1) The relative importance of the two pathways of exposure. There is much disagreement about the relative importance of ingestion and inhalation in contributing to overall lead exposure. The OSHA regulation implicitly treats inhalation as most important in that the primary control measures are set to reduce exposure to lead in the air; however, hygenic measures are also accorded an important place, and the justification for the regulation notes that the amount of lead available for ingestion is likely to be roughly proportional to the air lead level. The model used by OSHA in setting the regulation also assumes that inhalation is the primary route of occupational intake. Many industrial hygienists and environmental officers working for the lead industry believe that ingestion is the more important pathway; they believe that they can correlate observations of worker carelessness with higher blood lead levels, and they cite a recent study of Japanese battery manufacturing[4] in which it is suggested that the principle cause of lower blood leads in Japanese workers is intensive hygiene measures. Unfortunately the data in that report are not sufficient to draw a firm conclusion, and the industry wide data that are needed to resolve this issue, most importantly information on particle size distributions, are lacking.

2) The effectiveness of the various control measures. The disagreement over the relative importance of inhalation and ingestion immediately leads to disagreement over the expected effectiveness of certain controls. If inhalation is less important, then controls on air lead levels may not have a great effect; some lead industry hygienists suggest that the principal contribution of respirators is to act as a barrier so that workers will not put their hands in their mouths. There is further disagreement over the effectiveness of medical monitoring and removal in protecting health. Part of the difficulty that some see in relying on removal schemes is that at feasible removal triggers and a tolerable frequency of monitoring, some damage may be allowed to occur prior to removal. In general industrial specialists tend to claim that controls "downstream" in Figure 1.2, that is controls applied to individual workers such as respirator protection, hygenic measures, and medical surveillance, are more effective (and less costly) because they are better targeted to the people at high risk of suffering harm, while labor and

regulators tend to favor "upstream" controls--controls on emissions and the provision of isolation areas--that do not require the worker to bear as much of the burden/responsibility for control.

3. The nature and severity of harm at various exposure levels. The history of medical appreciation of lead hazards has followed a relatively typical course for occupational health concerns: improvements in medical measurements and more epidemiological data keep providing new evidence that some harm may be caused by lead exposures at levels lower than was previously thought. Only a few years ago it was accepted practice to assume that blood lead levels below 80 ug/100g were "safe". Now OSHA's target level for concern is 40 ug/100g and the final medical removal trigger requires removal from high exposure areas if blood lead levels are consistently over 50 ug/100g. At the lower levels of exposure the evidence of adverse health effects becomes more tenuous, the nature of the harm less clearly defined, and there is ample room to disagree about what constitutes significant risk to health.

4. The feasibility and costs of various control measures. In addition to debate over whether emission-reducing engineering controls are directed at the most important pathways of exposure, there can be debate over whether the control will work, whether the cost estimates are accurate, and whether the costs as estimated are affordable. Large capital investments in new process technology in particular can be risky both in terms of how well they will work, and in terms of how soon they can be made to work well.

1.3.3 Policy Issues

The summary in the previous section suggests that much of the debate on technical issues is fueled by disagreements over industrial and regulatory policy. We divide those disagreements into two categories:

1. Nature of the regulations. Perhaps the single most divisive issue is what is to be the nature of the primary standard: in the present regulation, the primary standard is the permissable exposure level (PEL), which is based on an "upstream" measurement, air lead levels. Labor strongly favors such an approach. Management, in contrast, favors a standard based on the "downstream" measurement, blood lead levels, on grounds that such a standard would give them the maximum flexibility to protect workers in a cost effective manner. Labor and OSHA have argued in reply that a blood lead measure is insufficiently protective for standard setting (because of individual variability in blood lead response to air lead levels, enforcement problems, delays between dangerous changes in air lead levels and the time those are reflected in blood lead levels, and the

fact that blood lead levels do not immediately identify the source of emission requiring control) and places too much of the burden of health protection on the individual worker. Other policy disagreements occur over the setting of the PEL:

o Industry argues that it places an unreasonable burden to set a level which can not be met in a number of areas, which requires them perennially to demonstrate the lack of feasibility of compliance, and which leaves open the possibility that at any time they may suddenly be required to make a capital investment newly declared to be feasible. OSHA and labor argue that the lower level is necessary because of the health benefits where compliance is feasible, and to spur the development of the necessary technology for the remaining areas.

o Still further disagreement occurs over the medical removal provision: industry argues that the trigger levels are unnecessarily stringent, too inflexible and do not take account of production losses from rotation of skilled workers. They also object to the requirement that they pay a high salary to a worker transferred to a lower rated job, or even laid off.

2. Implementation of control measures. The lead regulation is unusual in that it envisioned a very long period of time for complete implementation of the required control measures; it is less unusual in that the implementation of many requirements has been delayed by litigation and the granting of variances. In the debate over the times required for compliance a number of policy questions have been raised.

o To what extent do the regulations offer room for investment in new technology which might in the long run provide greater protection to workers and offer benefits in increased productivity, but whose implementation will take time and whose effectiveness is uncertain?

o Can worker health be adequately protected in the meantime?

o What sort of mechanisms are there to protect industry from some of the risks of investing in new technology for control purposes, such as uncertainties in the effectiveness of new controls and uncertainties in the future nature and enforcement of regulations?

o Have cutbacks in enforcement and recent proposals to weaken the regulations encouraged non-compliance on the part of some firms?

1.3.4 Industrial Philosophy, Social, and Ethical Issues

The policy questions just discussed fit into a more general context in which differences of opinion on policy reflect differences in people's views about the nature of the American economy and about a variety of social value issues. We would like to mention a few of these issues here because we believe that this context is useful for understanding some of the bitterness of the debate on technical and policy questions; however, we do not attempt to discuss them further in our report.

1) Scope of industrial regulation. The OSHA lead regulation touches on a number of areas which are widely held to be management prerogatives, worker prerogatives, or jointly to be negotiated between management and labor. These include decisions on capital investment in production equipment, wage and personnel assignment policy (affected by MRP), and matters of personal hygiene. Management's and labor's concerns are each subordinate to their broader concerns, return on investment and productivity, or wages and benefits, job security, and working conditions. As a result debate over a particular health measure can easily hinge on one or both party's unwillingness to concede on a matter of principle, rather than the merits or actual costs of the particular measure: examples are the acrimony in the debate over potential payments of wages to workers laid off under MRP, and the arguments over the provision of air conditioning for isolated control areas.

2) Biological monitoring of individual workers. As noted above the lead industries would prefer to have a standard based on individual blood lead measurements; we will argue later that at least during the implementation of the lead standard to date, it has been blood lead measurements and the possibility of significant numbers of worker transfers mandated by the Medical Removal Provision, that has guided industry behavior not the permitted exposure level. (In part, this has been because of the long lead time--up to ten years--provided in the standard for reduction of air levels in the industries with the most serious problems.) In addition to the questions that may be raised about the effectiveness and enforceability of a biological standard, there are broader questions. Are there rights to privacy that are being invaded? Is the individual worker unfairly at risk, either of job loss or of health damage, if he/she is both the indicator of level of protection and the person being protected?

3) Sensitive workers There is considerable variation in the rate at which workers absorb lead under specified conditions of exposure. There is further variation in the amount of health damage produced by an amount of absorbed lead. These differences can come from biological differences, from differences in sex or age, or from differences in behavioral patterns (smoking,alcohol,diet,hygiene). Some fear that babies born to both male and female lead exposed workers can be harmed either as a result of genetic defects or fetal damage. Two questions arise. To what extent is special treatment of sensitive populations appropriate or justifiable? (Present day practice sometimes includes the firing of "rapid absorbers" during an initial probationary hiring period and the exclusion of female workers from high lead exposure jobs.) To what extent is the present mandate of the OSHAct to protect sensitive workers, (when feasible), essential to providing a margin of safety for the bulk of the population?

1.4 Summary of Conclusions and Recommendations

Our conclusions fall into four categories: conclusions about the implementation of the lead standard to date, conclusions about the prospects for future implementation, recommendations for future occupational lead policy, and observations about how the results of our study might generalize to other occupational health hazards. We devote a subsection to each.

1.4.1 Implementation of the Lead Standard to Date

From the record we have examined to date we have made the following observations:

o Both air lead and blood lead levels have come down significantly since the promulgation of the lead standard (Section 3.2 and 3.3, pp. 3-3 to 3-15). In the most affected industries (primary smelting, secondary smelting and batteries) the numbers of workers over 60 ug/100g at any one time have been reduced between three and ten fold--from about 7,000 in 1977 to about 700 in 1981. The numbers of workers over 40 ug/100g in the three industries has been reduced from about 17,000 in 1977 to about 12,500 (neglecting changes in the total numbers employed in the industries). Finally, whereas before the standard there used to be an appreciable number (a few percent) of workers over 80 at any one time, such blood lead levels are now practically unknown.

o Particularly in view of the substantial reductions in the numbers of workers over 60 and over 80 ug/100g, it is likely that there have been major corresponding reductions in adverse health effects.

o In none of the three industries is there yet compliance with the long term mandated air lead level of 50 ug/m^3 through engineering controls, work practices and administrative controls. In primary and secondary smelting compliance with the old standard of 200 ug/m^3 has not yet been achieved (Section 3.2, pp. 3-3 to 3-9).

o There has been substantial implementation of controls of all types listed in Table 1.1. (See Sections 3.2, 3.5 and 3.6).

o The current level of expenditures for controls appear to be running at about the level of $1000-1500 per exposed worker per year in capital investments for categories A and B as defined in Table 1.1. (See Section 3.6.1, p. 3-49). Ongoing expenditures for clothing, laundry, and other hygenic expenses are roughly $700 per exposed worker per year. Respirators presently cost roughly $300 per worker per year (although some maintain that a respirator program in full compliance with the regulation costs as much as $1000 per worker per year). Monitoring and medical surveillance cost $500 per worker per year, while the costs of transfer or removal under the latest MRP triggers are likely to run about $300-600 per exposed worker per year (Section 3.5, pp. 3-28 to 3-48).

o The number of additional workers hired to temporarily replace people transferred or removed under MRP has been too small to have had much direct effect on average blood lead levels; however, the existence of the trigger levels as targets and the large potential costs of having to make substantial numbers of transfers and/or layoffs has been an important driving force behind most of the implementation of controls (Section 3.5, pp. 3-28 to 3-48).

o There is no evidence of widespread firings of workers with high lead accumulations from past exposures because of the MRP provisions (Section 3.5, pp. 3-28 to 3-48).

o The reductions in blood lead levels have been roughly consistent with OSHA's predictions for the first three years of effective compliance with the standard (Section 3.3, pp. 3-10 to 3-15).

o 30-50% of the observed reduction in average blood lead levels may have resulted from a reduction in environmental exposure due to controls on the use of lead in gasoline. This effect was not anticipated in OSHA's predictions prior to the promulgation of the standard (Section 2.6 and 3.4, pp. 2-33 to 2-35 and 3-16 to 3-27). However the major reduction in the number of workers at particularly high blood lead levels (over 60 ug/100g) is more largely due to the operation of the OSHA lead standard.

o When the reduction in environmental exposure is taken into account, the observed reductions in air lead levels are sufficient to explain the remaining reduction in average blood lead levels. Alternative explanations of the decline in blood lead could only be justified by further analysis of the dynamics of lead absorption with more data on particle size distributions (Section 3.4, pp. 3-16 to 3-27). This is not to minimize the importance of management and hygenic measures. They clearly contribute. However the data do not compel us to attribute much of the decrease in average blood lead levels to more effective hygienic measures adopted after the promulgation of the standard, at least through 1981.

o After considering the effects of the reductions in environmental exposure on the predicted declines in worker blood lead levels, currently observed distributions of blood lead levels appear to be consistent with three years of effective compliance with a 100 ug/m^3 limit on effective worker exposure--instead of the 50 ug/m^3 prescribed by the standard. Since effective compliance using respirators and other controls was required immediately, there is evidence that the lead industry is still some distance from achieving the worker exposure levels mandated by the standard (Section 3.4, pp. 3-16 to 3-27).

1.4.2 Prospects for Future Improvement

We have made the following observations about the opportunities for further reducing worker lead exposures:

o There are opportunities for substantial further control of lead exposures. These measures are not inexpensive (overall, annualized costs amount to about $5,000-10,000/worker according to the Charles River Report), although there are appreciable opportunities for comparatively low cost investment in isolation-type controls. These costs would be incurred at a time when the lead industries are undergoing severe economic hardships (Sections 3.6.3 and 3.6.4, pp. 3-55 to 3-75).

o In many cases new process technology offers the prospect of better control of occupational exposures coupled with increased productivity; however, there are substantial additional risks associated with such investments which will impede their adoption in the absence of external incentives (Sections 3.6.3 and 3.6.4, pp. 3-55 to 3-75).

o Whatever controls are introduced, certain job categories will continue to experience air levels significantly in excess of the 50 ug/cubic meter permissible exposure limit.

1.4.3 Recommendations for Control of Lead Hazards

Based on the observations summarized in the previous two subsections we have two general recommendations for improving occupational health in the lead industry.

First, the data we have analyzed so far tentatively suggest that the most effective measures for further reducing occupationally absorbed lead are measures which reduce air lead levels. We therefore recommend that, as provided in the current standard, where air exposures are above a relatively stringent PEL (preferably the current 50 ug/m^3), all "feasible" engineering, work practice, and administrative measures should be utilized to reduce exposures. It should be recognized that the 50 ug/m^3 level will not be fully achieved with such control measures for all job categories.

Second, we believe that there should be a deliberate societal consensus-building process for arriving at what is "feasible". We see three interrelated problems for the lead-producing and lead-using industries that cannot be solved in isolation from one another:

o The high cost of controls required to address occupational and environmental health concerns (at least in the primary smelting industry, there is considerable overlap in the measures that reduce external discharges and worker exposure).

o The major current financial distress of the affected industries (primarily caused by market factors--not by the regulatory requirements themselves)

o The legacy of bitterness and distrust from many years of labor/management and industrialist/environmentalist confrontation.

The general public also has a stake in the outcome of this process. There is a societal interest (1) in occupational and environmental health as a matter of the general welfare and fairness, (2) in maintaining U.S. technical capability and comparative advantage in lead production technology, and (3) in maintaining access to substantial lead production within the country for possible national security needs. In view of these general societal interests, it may be reasonable for there to be some governmental underwriting (such as loan guarantees) of the risks of developing and applying new lead production technology. For those establishments planning to invest in substantial new technology, some short-run regulatory relief might be in order with respect to controls on existing equipment.

We suggest that these issues are best addressed in an explicit consensus-building process that would bring together all of the interests concerned--bringing authorized representatives of management and labor from the industries concerned together with EPA, OSHA, and other governmental entities as needed to work out a definitive long term agreement. To some extent, this is already being done through the mechanism of detailed tripartite (management/labor/OSHA) agreements for the implementation of control programs. Such an agreement has been worked out for the four plants of one primary smelting company (ASARCO) and it is our information that all the other primary smelting companies and their unions have agreed to enter into detailed talks to reach similar understandings. Recently the trade association for the secondary smelting industry has also agreed to be a party to similar talks.

1.4.4 Implications for the Regulation of Other Substances

Lead is virtually unique in the large amount of data available on worker exposures; however, its properties as an occupational hazard are similar to those of many other metals, and not very different from other workplace chemicals. We would like to mention two generalizations from our study of lead:

- Respirator programs provide only limited protection against exposure averaged over actual working conditions. By comparing data on air lead levels with data on exposure measured through blood lead levels, we have found that typical protection factors provided by respirators range from about 2 to 12. These are significantly lower than what laboratory tests indicate are feasible, but are in line with previous field measurements for other particulate exposures in actual practice. Hence the reliance on respirators to make major reductions in exposure appears inadvisable. (Section 3.4, pp. 3-16 to 3-27).

- The possibility that automated processes can both increase productivity and reduce exposures seems likely to hold for many industries. As in the case of lead, some explicit industrial planning (and governmental assistance, where warranted by substantial general public interests) may be worthwhile to meet occupational health goals while improving the economic status of affected industries.

1.5 Structure of the Report

The report consists of two further sections. Section 2 provides historical background on occupational lead exposure problems and regulations. Then Section 3 reviews evidence from publicly available sources and our case studies on the current implementation of the OSHA lead standard, compares actual blood and air lead reductions with projections made by OSHA prior to the adoption of the lead standard, and considers prospects for further progress in reducing exposures.

References for Section 1

1. 43 Federal Register 54354 et seq. November 21, 1978

2. "OSHA Raises Engineering Control Level, Extends Compliance Period in Draft Rule." Occupational Safety and Health Reporter Bureau of National Affairs, April 7, 1983, p. 941-2

3. Charles River Associates. Economic and Environmental Analysis of the Current OSHA Lead Standard Report to the Ocupational Safety and Health Administration, CRA Project No. 5356.60, September, 1982

4. D.J. Burton, "Administrative Controls and Management Practices used to Minimize Lead Inhalation and Ingestion in Japan," Radian Corporation, Salt Lake City, July 31, 1981

2. HISTORY AND BACKGROUND: OCCUPATIONAL LEAD EXPOSURE, EFFECTS, AND REGULATION

2.1 Introduction

Lead has been mined, smelted and refined for several thousand years. For the most part the lead was produced as a byproduct of silver production and even today silver and other metals account for roughly half to two thirds of the value of the output of a lead smelter. For typical ores several hundred tons of lead are produced per ton of silver. (See Appendix B).

From classical times lead has had numerous uses: lead oxides were used in pottery glazes and paints; metallic lead was used for alloying, plumbing (the Latin word for lead is plumbus), ballast, solder, and sheathing in construction. The most important modern additions to this list, battery manufacture and lead alkyls (used as gasoline additives), are associated with automobiles.

Public health concerns about lead as an environmental poison have alternated with the discovery of new applications, causing oscillations in the demand for lead; thus the discontinuation of the use of lead for plumbing and for interior paints was followed by a rapid growth in demand for its use in batteries and gasoline. At present the lead industry again faces declining demand as the use of lead in gasoline is being phased out and lighter, longer lasting batteries are coming into use.

Chronic lead poisoning as an occupational hazard was probably recognized by Hellenistic physicians[1,2]. It was extensively studied in the nineteenth century. A few quotes from the 11th edition of the

Encyclopedia Brittanica show that British authorities at the beginning of the twentieth century grappled with many of the same issues that concern us today.

- On variation in absorption due to the solubility of lead:

A) "Dr. M'Aldowie, senior physician to the North Staffordshire Infirmary, has stated that "in the pottery trade lead is very slow in producing serious effects compared with certain other industries."

- On individual variation in absorption:

B) "In his experience the average period of working in lead before serious lesions manifest themselves is 18 years for females and 22 1/2 years for males. But some individuals fall victims to the worst forms of plumbism after a few months' or even weeks' exposure to the danger. Young persons are more readily affected than those of mature age, and women more than men. In addition, there seems to be an element of personal susceptibility, the nature of which is not understood. Some persons ‘work in the lead' for twenty, forty or fifty years without the slightest ill effects; others have attacks whenever they are brought into contact with it."

- On the relative importance of inhalation and ingestion:

C) "Lead enters the body chiefly through the nose and mouth, being inspired in the form of dust or swallowed with food eaten with unwashed hands. It is very apt to get under the nails and is possibly absorbed in this way through the skin. Personal care and cleanliness are therefore of the greatest importance. A factory surgeon of great experience in the England Potteries has stated that seventeen out of twenty cases of lead-poisoning in the china and earthenware industry are due to carelessness (The Times, 8th October 1898)."

- On medical monitoring:

D) "In the annual report of the chief inspector of factories for 1897, it was stated that there had been ‘material improvement in dust conditions' in the potting industry, but ‘of lead poisoning unfortunately the same could not be said, the number of grave cases reported and particularly cases of blindness, having ominously increased of late.' This appears to have been largely due to the erroneous inclusion among potting processes of ‘litho-transfer

> making,' a colour industry in which girls are employed. New special rules were imposed in 1899 prohibiting the employment of persons under fifteen in the dangerous process, ordering a monthly examination of all women and young persons working in lead by the certifying surgeon, with power to suspend those showing symptions of poisoning, and providing for the more effectual removal of dust and the better enforcement of cleanliness."

o On economic feasibility:

> E) "... but it is a long step from individual experiments to the wholesale compulsory revolution of the processes of manufacture in so large and varied an industry, and in the face of foreign competitors hampered by no such regulations. The materials used by each manufacturer have been arrived at by a long process of experience, and they are such as to suit the particular goods he supplies for his particular market. It is therefore difficult to apply a uniform rule without jeopardizing the prosperity of the industry, which supports a population of 250,000 in the Potteries alone. However, the bulk of the manufacturers agreed to give up the use of raw lead, and to fritt all their glazes in future, time being allowed to effect the change of process; but they declined to be bound to any particular composition of glaze for the reasons indicated."

o On the effect of medical monitoring and shifts in the workforce:

> F) "In 1908 Dr. Collis made an inquiry into the increase of plumbism in connextion with with smelting of metals and he considered the increase in the cases of poisoning reported to be due to the third schedule of the Workmen's Compensation Act, (1) by causing the prevalence of pre-existing plumbism to come to light, (2) by the tendency this fostered to replace men suspected of lead impregnation by new hands amongst whom the incidence is necessarily greater."

The major new development after the turn of the century was the widespread use of measurements of lead in blood and urine to provide both an indicator of exposure and a benchmark that might be related to physiological harm. The availability of such indications as well as the feasibility of making simple measurements of air concentrations of lead, has meant that it is now possible to establish quantitative limits on exposure. These can be either environmental standards (limits on the concentrations of lead in air) or biological standards (limits on blood lead concentrations). In either case, it becomes possible to identify excess exposure as it is occurring, without waiting for the appearance of overt symptoms of lead poisoning.

In this section of our report we take a look at the present day understanding of occupational lead exposure and recent attempts to regulate it. The section is divided as follows: Part 2.2 describes the health effects expected at various levels of exposure to lead; Part 2.3 describes how lead is absorbed, stored and excreted in humans and some implications for control; Part 2.4 describes the various lead-producing and lead-using industries, the occupational exposures found in them, and the economic conditions under which they are currently operating; Part 2.5 describes the Occupational Safety and Health Administration regulations and the various issues that have been subject to litigation; finally, part 2.6 describes environmental exposure to lead, and the changes in exposure that have recently occurred.

2.2 Health Effects Of Lead 3,4,5

Lead has important health effects on red blood cell production, the nervous system, the kidneys and the reproductive system. The principle effect on blood is an interference in the synthesis of heme--needed for hemoglobin and a variety of other important heme-containing proteins. There are two types of interference: with the enzyme aminolevulinic acid dehydrase (ALAD) and with the incorporation of iron into protoprophyrins.

These interferences can be detected at low levels of exposure through measurements of elevated levels of aminolevulinic acid (ALA) or free erythrocytic protoporphirins (FEP) in the blood. At somewhat higher levels of exposure, anemia is seen in some individuals.

The effects on the nervous system at high exposures give rise to the classic symptons of lead poisoning: palsy, colic and digestive disturbances, a loss of motor control of the forearm, wrist, and fingers called "wristdrop". In extreme cases, convulsions and blindness can occur, and occasionally death. At lower levels of exposure, nerve conduction is slowed, there is some evidence of psychological effects (nervousness, irritability and, in children, impaired mental development). Effects on the nervous system are likely to be irreversible, at least in part.

The effect on the kidneys is basically a progressive reduction in function, sometimes accompanied by nephritis. This lowers the body's ability to excrete lead, and thus perhaps aggravates other harmful effects of lead exposure. Poor kidney function also may lead to hypertension and other problems[6].

Effects on the reproductive system take several forms. Lead crosses the placenta, but there is little direct evidence that lead causes fetal malformation. However there is evidence that lead exposure produces an increase in stillbirths and spontaneous abortions. In addition there is evidence that lead exposure causes chromosomal damage and loss of fertility in men.

Lead levels in blood are not a direct measure of any of these effects, not even the effects on blood production. Instead, blood lead represents a few percent of the lead stored in the body; at equilibrium, lead has a mean residence time in the blood of about 30 days, so that blood lead is probably best thought of as primarily an indicator of exposure in the previous month or so, although a portion of the blood lead level reflects a continuing input from long term storage in bones and elsewhere. We will discuss this in more depth in the next part (Section 2.3).

As a measure of exposure to lead, particularly when the level of exposure has been relatively constant, blood lead should correlate reasonably well with health effects; that is, one would expect reasonably well defined dose-response relationships for populations exposed to lead. It is important to note, however, that these correlations are statistical; there is a great deal of variation in sensitivity from one individual to another. Both the EPA and OSHA have reviewed the literature on dose-response relationships for lead exposure, and we summarize their conclusions in Table 2.1. Table 2.1 enumerates the lowest blood lead levels at which a significant incidence of effects on each physiological system have been observed. It lists these levels for both children and adults. Although our concern is with occupational exposures which nowadays only affect adults, effects on children are of interest as an indication of how sensitivity to lead can vary, and because studies have shown that it is not uncommon for lead workers to bring home enough lead to significantly affect their children[7].

Blood lead is today the biological indicator of choice for exposure to lead. However, blood lead levels vary considerably, both from individual to individual and for a particular individual under similar

Table 2.1
Summary of EPA and OSHA Judgments on Lead Health Effects[3,4]

Nature of Effect	Blood Lead Level Range Where Effect Has Been Measured* Adults	Children
Red Blood Cells and Their Precursors		
Inhibition of an enzyme important in heme synthesis (ALAD)	some inhibition below 20 ug/100g; at a blood level of 40 ug/100g more than 20% of people have over 70% inhibition of this enzyme (no known clinical consequences)	10 ug/100 ml (regarded as "adverse to health" at 40 ug/100 ml)
Buildup of free erythrocyte protoporphyrin (FEP)-- a precursor of heme	15-20 ug/100 ml (women) 20-25 ug/100 ml (men) (no known clinical consequences)	15-20 ug/100 ml
Anemia (Reduced hemoglobin in circulation)	about 50 ug/100 ml	40 ug/100 ml
Nervous System		
Cognitive deficits		50-60 ug/100 ml*
Fatigue, nervousness, sleep disturbance	Observed in 56% of a group of workers averaging 60 ug/100; "protective threshhold" set at 40 ug/100g	
Peripheral neuropathies (abdominal pain, weakness in extremities	50-60 ug/100 ml	
Slowing of nerve conduction	50-59 ug/100g	
Encephalopathic symptoms (delirium, mania, convulsions, coma, death)	100-200 ug/100 ml	80-100 ug/100 ml

---

*A recent study by Needleman[8] found that a group of second grade students with relatively higher lead levels in teeth (used as an index of long term exposure to lead) had lower IQ scores and a greater incidence of undesireable classroom behaviors ("distractable", "impulsive", "does not follow a sequence of directions") than classmates with lower tooth lead levels. Single blood lead levels done several years before in some of the students with the highest tooth lead group averaged 35 ug/100 ml with a high value of 54 ug/100 ml. The comparison group with low tooth lead averaged 23.8 ug/100 ml.

Table 2.1, Continued

Nature of Effect	Blood Lead Level Range Where Effect Has Been Measured*	
	Adults	Children
Kidneys		
Progressive loss of function not detectable by ordinary medical screening tests until about 2/3 of kidney function is destroyed; 85 % loss of kidney function requires dialysis, lesser loss produces increased risk of hypertension and resulting cardiovascular disease	long term exposure to levels over 40 ug/100 ml but well below 80 ug/100ml; it was estimated that 10% of lead workers have appreciable lead nephropathy. (19 workers so classified averaged 30-50% loss of function.)	
Reproductive System		
Decreased quantity and quality of sperm, leading to diminished fertility	Found in a group of workers with mean blood level of 41 ug/100 ml; many in this group were at 30-40 ug/100 ml	
Excess risk of abortions, from mutations carried in sperm, excess risk of fetal damage from direct exposure of pregnant women	Blood lead levels should be maintained below 30 ug/100 ml in both prospective parents for protection against these effects	

conditions of exposure. This is not too surprising in view of the complicated balance described in part 2.3. Furthermore, quality control of blood lead measurements has been a significant problem. Consequently other indicators of exposure have been sought and evaluated. Lead in urine shows even greater variablity than blood lead: it is strongly affected by immediate past exposure, by changes in diet and consumption of liquids, and by the health of the kidneys (which can be impaired in individuals with prolonged lead exposures). The effect of lead on hemoglobin synthesis provides candidate indicators: ALA in urine, FEP in blood. The latter is the most convienient for routine screening, by measuring zinc protoporphyrins (ZPP). These tests also appear to be of limited incremental value as indicators of lead exposure because they do not appear to correspond any better than blood lead with physiological effects (other than heme synthesis) and because their levels become elevated from other causes of anemia. Furthermore there are problems with quality control in ZPP measurements fully as serious as those for blood lead. Even so ZPP does measure actual physiological change relating to lead in blood marrow and so it may provide information which can usefully supplement blood lead measurements.[9]

2.3 The Dynamics of Lead Absorption, Storage, and Excretion

Lead is absorbed into the blood stream with varying efficiencies after being taken into the body through breathing, eating, and drinking. It is stored primarily in the skeleton, but also in the blood, in the nervous system, and in various organs including the kidneys and liver. It is excreted through urine, feces, and in small amounts from hair, nails, and sweat. The dynamics of these processes are complicated because various parts of the body exchange lead with blood at different rates. Rabinowitz[10] and Bernard[11] have made dynamic models for these processes. The Bernard model, adapted by OSHA and used in estimating the costs of medical removal[12], represents the body by five storage compartments for lead--one compartment that essentially corresponds to the blood stream and four others, each with its own exchange rate for lead with lead in the blood. There is considerable controversy over the use of the Bernard model, the Rabinowitz model or any of the numerous attempts to directly fit empirical relationships between air concentrations of lead and blood lead levels. The controversy involves both questions about the dynamic behavior of the models and questions about the estimates made of lead absorption from the air, and covers such matters as the validity of animal data, the relative importance of inhalation and ingestion, particle size distributions and particle solubility. Independent of the details of the model used, certain qualitative features of human absorption and excretion of lead seem clear:

o The bulk of the lead in the body is stored in bones and elsewhere over long periods of time; a significant fraction of this lead has a residence time of decades. The concentrations of lead in bone generally increase over the first several decades of life. True equilibrium for lead in the body therefore rarely occurs. However, a slowly evolving "dynamic equilibrium" (a rough balance between daily intake to blood and daily outflow from blood through the urine and to long term storage in bone) can be expected to be observed for members of the general public and for those workers who have roughly constant average exposure to lead over periods of a few years.

o Rapid changes in exposure (starting or stopping occupational exposure, for instance) produce relatively rapid initial changes in the levels of lead in the blood and in organs in near equilibrium with the blood. The time scale for such changes is typically a few weeks.

o Given this time-scale for achieving a rough dynamic equilibrium, the daily absorption and excretion of lead are typically 2-4% of the lead stored in short term compartments (e.g. blood).

o Lead absorption to the bloodstream from adult non-occupational exposures varies considerably depending on diet, smoking habits, and ambient air lead levels; typical values are 30 - 40 ug/day [ref. 9, p. 119, ref. 11].

o It is difficult to precisely calculate absorption from occupational exposures even given an average air lead concentration, because breathing rates vary among individual workers, the amount absorbed through breathing depends on the size distribution of the lead particles, and because it is difficult to estimate how much lead will be ingested from the dust in the environment. OSHA's assumptions were that on average an eight hour exposure to 50 ug/m^3 would lead to a daily absorption of about 110 ug.

We illustrate these observations with Figure 2.1 which shows the expected long term rises in blood lead for long term occupational exposures at air levels of 50 ug/m^3 and 200 ug/m^3. In Figure 2.2 we show a simplified version of the flows and storage of lead assuming only two storage compartments, short and long term, for someone with a long term exposure to lead at an air level of 50 ug/m^3. Both of these figures use OSHA's assumptions and the Bernard model[12]; however, the qualitative behavior and approximate values of the numbers (which are all we are trying to illustrate) are not dependent on the model. Two simple conclusions can be drawn immediately from these figures. Because daily intake is a relatively small fraction of the amount stored even in the short term compartments, it is difficult to produce a large rise in blood lead level in less than a week or so. Second, because the exchange between long term and short term compartments can contribute a significant fraction of the lead in short term compartments after prolonged high level exposure, long term buildup of lead can be a significant problem for

From Ashford, Gecht, Hattis, Katz
CPA 77/11

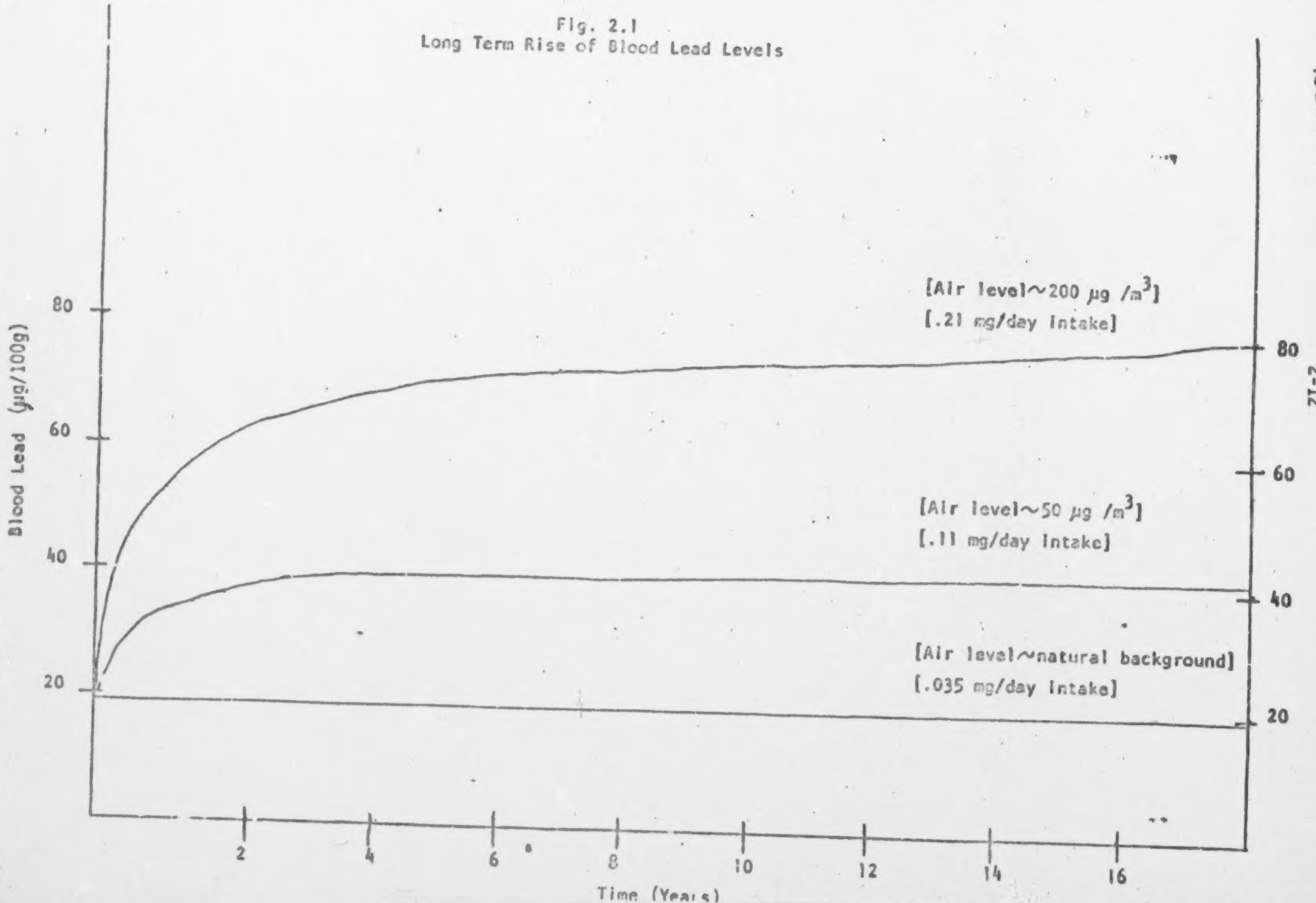
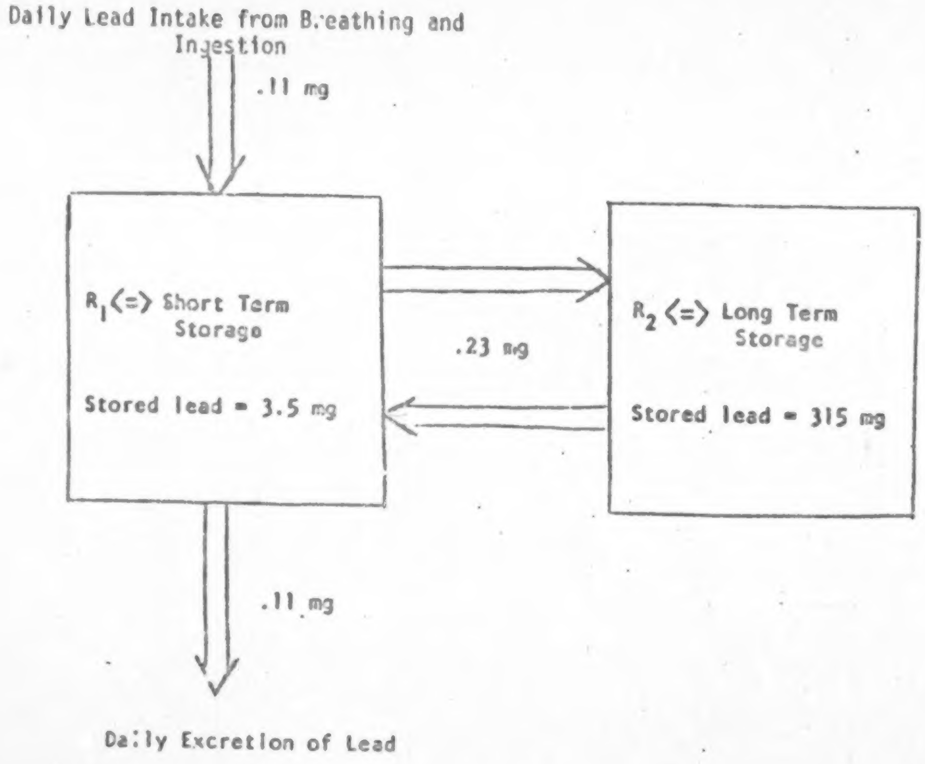


Fig. 2.1
Long Term Rise of Blood Lead Levels

Figure 2.2 Equilibrium Lead Storage and Flows for an Individual Exposed for Several Decades to Lead in Air at a Concentration of 50 $\mu g/m^3$ at Work


Daily Lead Intake from Breathing and Ingestion
.11 mg
R_1 <=> Short Term Storage
Stored lead = 3.5 mg
.23 mg
R_2 <=> Long Term Storage
Stored lead = 315 mg
.11 mg
Daily Excretion of Lead

Adapted from Ashford, Gecht, Hattis, Katz
CPA 77/11

people who work in the lead industry for many years. For such workers, blood lead levels may fall only very slowly after removal from high exposure areas.

In setting the occupational standard for lead, OSHA collected information on the existing distribution of air lead levels and blood levels for various industries. The results for primary and secondary lead smelting and battery manufacture are shown in Tables 2.2, and 2.3, for air and blood respectively. The tables show that at the time of promulgating the standard there was widespread violation of the previous standard which required air levels to be less than 200 ug/m^3, and there were significant numbers of workers whose blood lead levels showed they were at risk of adverse health effects as listed in Table 2.1.

The next step for OSHA was to use an adaptation of the Bernard model to estimate the change in the numbers of workers at various blood lead levels under certain assumptions about compliance with proposed air lead standards[12]. The results of this analysis are shown in Figure 2.3. It should be noted that these calculations assumed long term equilibrium, and so, in effect, were expected to hold only after a substantial fraction of the existing highly exposed labor force had retired and been replaced with new workers with lower exposure histories.

Table 2.2
Air Lead Exposures in Selected Industries Before the New
OSHA Lead Standard* (1977)

Industry	Total No. Exposed	Estimated Percentages of Exposed Workers in Various Air Lead Ranges**			
		under 100	100-200	over 200	Total
Primary Lead Smelting	2,200	18%	21%	61%	100%
Secondary Lead Smelting	3,200	21%	12%	67%	100%
Storage Battery Manufacture	16,700	57%	23%	21%	100%

---

*Under the pre-existing standard worker exposures were to be limited to an average of 200 ug/cubic meter over an eight hour day. (This standard was adopted at OSHA's inception in 1970 from prior voluntary industry consensus standards.)

**All air lead levels are in micrograms per cubic meter

Source: Based on information in Ashford, N.A., et al., The Effects of OSHA Medical Removal Protection on Labor Costs of Selected Lead Industries M.I.T. Center For Policy Alternatives report No. CPA-77/11, December 1, 1977

Table 2.3
Blood Lead Levels Among Exposed Workers in Selected Industries
Before the New OSHA Lead Standard (1977)

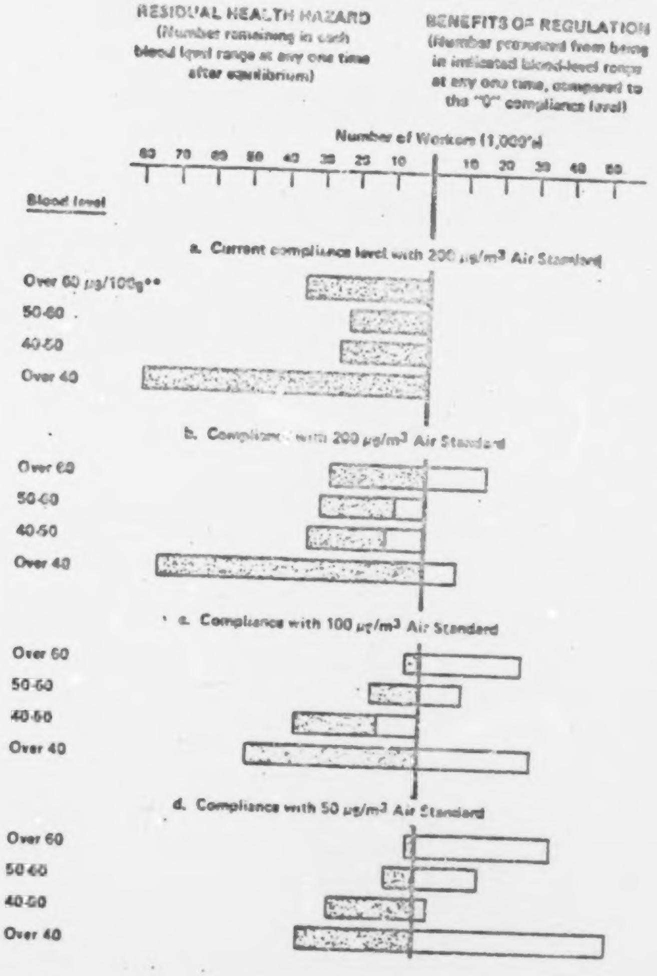
Industry	Estimated Percentages of Exposed Workers in Various Blood Lead Ranges*			
	Under 40	40-59	60-80	over 80
Primary Lead Smelting	27%	45%	26%	2%
Secondary Lead Smelting	29%	30%	25%	16%
Storage Battery Manufacture	20%	49%	25%	6%

* Blood lead levels in ug/100g

Source: 43 Federal Register pp. 54453-6, November 21, 1978

Figure 2.3

Best point estimate of ultimate equilibrium benefits of reducing air-lead exposures under different blood-lead level variability assumptions* (blood-lead standard deviation = μg/100g).



---

* Computations based on air lead-blood relationships predicted by Bernard Model and Assumption C and OBA's best point estimates of exposure.

** All blood-lead levels are in micrograms per 100 grams.

2.4 Structure and Economic Condition of Lead-Producing and Lead-Consuming Industries

As we said earlier, lead has numerous uses. It is non-corrosive, has a high specific gravity, has a low melting point, and has chemical characteristics suited to special applications. Its resistance to corrosion makes it useful for pipes and tubes; its high specific gravity makes it useful for weights and shot; its low melting point makes it suitable for manufacturing solder; its chemical characteristics make it suited for battery manufacture and for use as a gasoline additive. It is relatively abundant and occurs with other desirable metals so that the cost of lead is comparatively low.

Lead ores usually contain zinc, copper, and silver as well. A typical lead ore might contain 5% lead; a rich ore might contain 10-15% lead. The lead is recovered by milling, sintering, and smelting. In sintering the milled ore is heated to drive off the sulfur, then lead compounds are reduced in a blast furnace to nearly pure metal. A series of refining stages then separate other metals from the lead.

In many uses, such as batteries and pipes, the lead can be recovered after the item is discarded. This gives rise to a second production industry, lead scrap handling and secondary remelting or smelting. The major flows of lead for 1973 are shown in Figure 2.4. Imports and exports represent less than 10% of the flow; this reflects the high transportation costs of lead because of its high density. Since 1973 secondary lead production has been an increasingly large percentage of total lead production. This is illustrated in Table 2.4.[13] This trend has

TABLE 2.4
U.S. PRIMARY REFINED LEAD PRODUCTION VS. SECONDARY PRODUCTION*,+

	Primary Production**	Secondary Production (Old Scrap only***)	Total Production (excluding new scrap)	Secondary Production From Old Scrap as % Total Production
1969	594	468	1062	44.1
1970	615	459	1074	42.7
1971	604	444	1048	42.4
1972	624	452	1076	42.0
1973	624	489	1113	43.9
1974	620	545	1165	46.8
1975	580	512	1092	46.9
1976	597	564	1161	48.6
1977	551	637	1189	53.6
1978	568	650	1218	53.4
1979	573	673	1251	53.8
1980	548	581	1129	51.5
1981	495	546****	1041	52.4
1982(est.)	458	505****	963	52.4

---

*All production data is in thousands of metric tons per year. There are minor differences between this table and Table 3.1 for primary production for the years before 1979 because the data were taken from different Bureau of Mines Documents (pre-1979 data in this table come from referece 2. Data after 1979 were taken directly from refrence 1, from Table 3.1, or estimated from the information in Table 3.1.

**From Both Domestic and Foreign Ores

***The numbers in this column are about 85% of the corresponding numbers for total secondary production in Table 3.1. The numbers in Table 3.1 include secondary production from both old scrap" (e.g. old pipes from demolished buildings, used batteries) and "new scrap" (new but off-specification batteries, pipes, or shavings and cuttings generated in the production of those goods.)

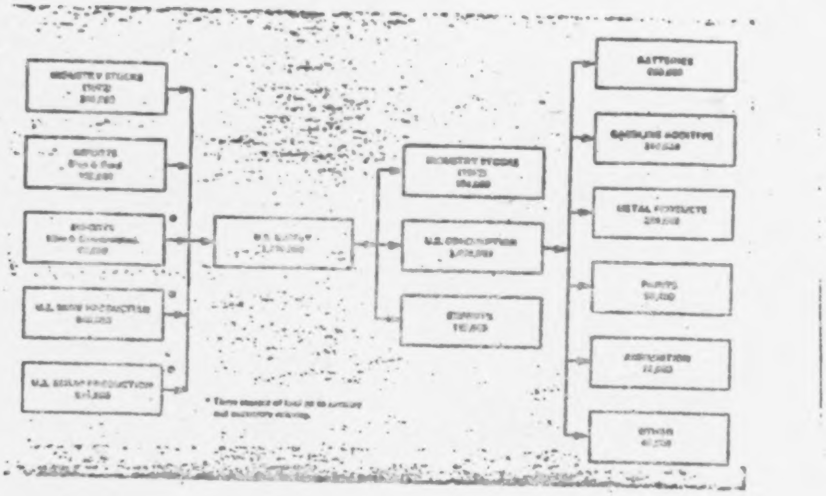
****Estimated as 85.2% of the total secondary production listed in Table 3.1.

+Ashford, Nicholas A., Dale Hattis, George Heaton, Jr., Barbara Richardson, Mary Ballew, W. Curtiss Priest, Environmental Regulation of Lead-New Developments since the Mid-1970s, CPA/WP-82-5, Oct. 15, 1982.

Figure 2.4

FLOW OF LEAD IN THE UNITED STATES (1973), IN METRIC TONS PER YEAR *,**

Reproduced from
best available copy.


INDUSTRY STOCKS (1972)
IMPORTS
IMPORTS
U.S. MINE PRODUCTION
U.S. SCRAP PRODUCTION
U.S. SUPPLY
INDUSTRY STOCKS
U.S. CONSUMPTION
EXPORTS
BATTERIES
GASOLINE ADDITIVE
METAL PRODUCTS
PAINTS
AMMUNITION
OTHERS

---

*D.R. Tierney et al., Status Assessment of Toxic Chemicals in Lead, (EPA-600/2-79-210h), 1979.

**All figures supplied by the U.S. Bureau of Mines 1974 Mineral Industry Surveys.

Table 2.5
Changes in Use Patterns of Lead Between 1976 and 1981

Use	1981 Consumption Thousands of Metric Tons	1981 Consumption as % 1976 Consumption
Uses Where Most Lead is Probably Recycled:		
Storage Batteries (Grids and Posts and Oxides)	770,152	103.1
Cable Covering	12,072	83.5
Brass and Bronze	13,306	86.6
Sheet Lead	19,355	87.2
Caulking Metal	5,522	48.8
Pipes, Traps	8,829	70.5
Type Metal	7,838	57.5
Casting Metal*	18,562*	305*
"Other" (Weights, Annealing)*	6,739*	29*
Recyclable Uses Other Than Storage Batteries	92,243	78.6
All Mostly Recyclable Uses	862,395	99.8
Uses Where Most Lead is Probably Not Recycled:		
Gasoline Antiknocks	111,367	51.2
Red Lead	13,186	83.0
Litharge	45,025	45.4
Ammunition	49,514	74.2
Solder	29,705	51.7
Bearing Metals	6,922	58.4
Terne Metal	3,971	267
Pigments	80,165	83.6
"Other" (Foil, Collapsible Tubes, Galvanizing, Plating)	2,363*	29*
Less Recyclable Uses Other Than Gasoline Antiknocks	231,671	64.6
All Uses Mostly Not Recycled	343,038	59.5
Other Uses (Not Classified)	21,862	74.4
Total Lead Uses	1,167,101	86.3

---

*Comparison between 1981 and 1976 likely to be inaccurate because of the change in product categories used by the Bureau of Mines.

SOURCE: Hattis, et al., Reference 13

resulted from the fact that recyclable uses of lead (batteries, etc.) have been relatively constant whereas dispersive uses (e.g. gasoline additives) have generally suffered serious declines, as can be seen from Table 2.5 [ref. 13, p. 3-10].

The major lead producing and consuming industries differ markedly in the extent to which they contribute to significant occupational lead exposures. The highest air lead levels are found in five industries: primary lead smelting, secondary lead smelting, battery manufacture, lead pigment manufacture, and nonferrous foundries.

An important question in considering the future prospects for occupational lead standards is the financial condition of the industry. There is a direct connection in that the number of people exposed and the intensity of exposure are a function of production levels, other things being equal. There are also indirect connections. To what extent can industry afford to purchase additional mandated control equipment? To what extent is the industry modernizing its processes? In general new processes are more automated and offer the prospect of reducing exposure levels. The ability of industry to bear the current costs of control of occupational exposures and to install new controls or production processes depends on the strength and stability of demand for its products and the security of its supply of raw materials; it also depends on the nature of its competitive market; how well placed it is to pass costs forward to consumers or backward to suppliers. The current recession with depressed demand in the automobile and construction industries together with the phase down in the use of lead in gasoline makes the immediate view of lead producing industry look bleak. This story can be seen in Table 2.6[14].

Table 2.6
Real (1982 Dollar) Prices, Production and Estimated Gross Revenue From Primary U.S. Lead Production

Year	Price, Unadjusted Dollars	Price, April 1982 Dollars (cents/lb) (New York)*	Primary Lead Production (Thousands of metric tons)	Estimated Real Revenue Flow to U.S. Primary Producers (Millions of 1982 Dollars Per Year)
1950	13.30	48.44	462	492
1951	17.49	57.19	379	478
1952	16.47	55.38	429	524
1953	13.48	45.95	424	429
1954	14.05	47.78	442	465
1955	15.14	51.37	436	493
1956	16.01	52.58	492	570
1957	14.66	46.81	484	499
1958	12.11	38.14	427	359
1959	12.21	38.37	310	262
1960	11.95	37.51	347	287
1961	10.87	34.27	408	308
1962	9.63	30.26	341	228
1963	11.14	35.12	358	277
1964	13.62	42.84	408	385
1965	16.00	49.34	380	413
1966	15.12	45.13	400	398
1967	14.00	41.71	345	317
1968	13.21	38.39	424	359
1969	14.93	41.76	580	533
1970	15.69	42.34	605	565
1971	13.89	36.3	590	472
1972	15.34	38.37	618	522
1973	16.31	36.07	612	487
1974	22.49	41.85	611	563
1975	21.52	36.65	578	466
1976	23.10	37.6	593	491
1977	30.74	47.15	549	570
1978	33.68	47.94	566	598
1979	53.03	67.05	578	854
1980	42.91	47.56	548	574
1981	37.10	37.06	495	404
1982	25.54**	25.54	517	291

---

*Adjusted to April, 1982 dollars using the Producers' Price Index for "all commodities."

**Prices were even somewhat lower through the first seven months of 1983, ranging between 19 and 22 cents per pound, but as of October the lead price has recovered to 25 cents per pound.

Sources: Metal Statistics, 1982 (Fairchild Publications), and Lead and Zinc Statistics, Monthly Bulletin of the International Lead and Zinc Study Group, Vol. 23, August, 1983 which gives historical prices (in 1982 dollars) and production levels for the primary smelting industry. However, the story is more complicated, since lead accounts for only a fraction of the value of the output of the smelters; other metals are also important (at present prices, these account for well over half of the revenue from primary smelting). The structure of the market is also relevant: primary lead smelting is oligopolistic; three firms own the six operating smelters. Secondary lead smelting is a confusing market: there are a large number of firms, but many of them are owned by purchasing industries (e.g., battery plants), and prices are strongly affected by what the primary smelters do. Furthermore it is likely that toxic waste regulation will mean that there will always be a need for the hauling and disposing of scrap batteries, which suggests that the secondary smelting industry might continue to operate even under conditions of depressed lead prices. The battery industry is tending toward consolidation with eight large firms dominating the market.[4]

2.5 History of the Regulation

2.5.1 Actions before Promulgation of the Standard

The OSHAct was passed in 1970. For toxic substances and harmful physical agents it requires the Secretary of Labor to

> set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employeee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life.[15]

The act did not set timetables for promulgating specific standards; however, it did require OSHA to adopt as mandatory regulations any existing Federal Standard or any national consensus standard within two years of enactment. These consensus standards were defined as occupational health standards which had been "adopted and promulgated by a nationally recognized standards-producing organization under procedures...that persons interested and affected by the scope or provisions of the standard have reached substantial agreement...which afforded an opportunity for diverse views to be considered...and has been designated as such a standard by the Secretary..."[16] The consensus standard for lead dates from 1957, when the American Conference of Governental Industrial Hygienists first set a value of 200 ug/m^3 (earlier levels had ranged from 150 to 500 ug/m^3). This TLV was adopted as a standard in 1969 by the American National Standards Institute, and on this basis OSHA adopted it as a mandatory requirement in 1971.[17] In January 1973, the National Institute for Occupational Safety and Health (NIOSH), issued a criteria document[17] that recommended that OSHA lower the exposure limits to 150 ug/m^3. NIOSH, part of the Department of Health and Human Services, is charged with, among other matters, developing the scientific basis for occupational health regulation. In 1975, OSHA and NIOSH jointly reviewed the literature on health effects of lead and recommended a still lower exposure limit without specifying the level. Based on that review and the 1973 criteria document, OSHA proposed an exposure limit of 100 ug/m^3, for lead in air, and a limit of 60 ug/100g for lead in blood. In 1978 NIOSH issued a new criteria document[2], which reaffirmed its earlier support of the air level of 100 ug/m^3 and the blood level of 60 ug/100g, but which expressed further concerns about health effects at lower levels of exposure. Based on information contained in the NIOSH 1978 criteria document plus a considerable amount of additional information that it developed itself and presented in extensive hearings, OSHA promulgated the current lead standard in 1978.

2.5.2 Provisions of the Occupational Lead Standard

The occupational lead standard has a large number of provisions.[3,18] They may be summarized in the following general categories:

Air exposure and monitoring The standard for exposure to lead in air, the permissible exposure limit (PEL), is 50 ug/m^3 averaged over 8 hours. This limit is to be satisfied through a combination of engineering controls, work practices,and administrative controls, with the exception that certain industries are permitted substantial periods of time before engineering compliance (e.g. primary smelting 10 years, secondary smelting and battery manufacture 5 years); during this period, compliance with the standard may be achieved through employee use of respirators. Monitoring of air level must be done over full shifts and be representative of the employees' actual regular daily exposure to lead. Quarterly mechanical ventilation monitoring is required. Respirator use under this provision was to be governed by a number of specifications including a requirement for quantitative fit testing, although this has been subsequently modified.

Hygiene, Work Clothing, and Housekeeping The employer is required to maintain the work environment as free from dust as is practicable. Showering facilities must be provided by the employer and showers are mandatory for workers exposed to lead at levels above the PEL. The employer must provide a temperature controlled positive pressure lunchroom. The employer shall provide change rooms, protective work clothing and cleaning and disposal of work clothing for employees exposed to air lead levels greater than the PEL.

Medical Monitoring and Removal The employer shall institute medical surveillance for all employees who are exposed to air levels greater than 30 ug/m^3 more than thirty days a year (the action level). The surveillance shall include, medical examinations, blood lead measurements and zinc protoporphyrin measurements every six months and more frequently if blood lead exceeds 40 ug/100g. Such blood determinations shall have an accuracy (95% confidence level) of +/- 15% or 6 ug/100g, whichever is greater. The employer shall make available medical examinations to employees who begin assignment to a lead exposed area (above the action level), to employees who have blood lead measurements greater than 40 ug/100g, to employees who expect to be having children, and in other circumstances where there are medical indications. Prophylactic chelation (the prescribing of drugs to induce excretion of lead) is forbidden. If an employee's blood levels are above prescribed levels or if there is a medical finding that the employee has a detected medical condition which places him/her at increased risk, he/she shall be removed to an area of lead exposure less than prescribed levels. During removal the employee shall maintain the earnings, seniority, and other rights as though he/she had not been removed. Return shall be when the worker's blood lead level falls to prescribed levels. The prescribed levels for removal, return, and exposure while removed are summarized in Table 2.7.

Table 2.7
Implementation Schedule for Medical Removal Protection

Year after adoption of standard	1	2	3	4	5+
Blood lead level for removal(ug/100g)	80	70	60	60	50 (ave. 3 samples or 6 months)
Blood lead level for reinstatement	60	50	40	40	40
Maximum air lead exposure level during "deleading" period ug/m^3)	100	50	30	30	30

If the blood lead levels do not fall to the prescribed level in 18 months, there shall be a final medical determination whether or not the employee may be returned to his former job.

Employee information and training For each workplace in which there is a potential exposure to airborne lead, the employer must provide information on lead and the lead standard to his employees. The employer shall institute a health training program for all employees exposed above the action level. He shall maintain records on all monitoring of employees and air levels

2.5.3 Recent Litigation Concerning the Lead Standard

The lead standard was promulgated in November 1978, with an effective date of February 24, 1979. It was immediately challenged, by the Steelworkers who claimed that the PEL of 50 ug/m^3 was too lenient, and by the Lead Industries Association (LIA) which claimed that there were a number of procedural irregularities, that OSHA had misused the available data, that the PEL was too stringent and not feasible, that a biological standard should have been imposed rather than the air PEL, and that MRP was not authorized under the OSHAct and was too burdensome. After a classic "race to the courthouse" the cases were consolidated in the U.S. Court of Appeals of the D.C. Circuit. The court ruled against all of these claims, although it remanded to OSHA the requirement that compliance with the PEL be by means of engineering controls, work practices, and administrative controls for a number of lead-using industries (not the major ones) which OSHA had not studied individually. For these industries, the court ruled that OSHA had not yet adequately demonstrated feasibility.

The debate over the appropriateness of a biological standard is still of interest today. The LIA argues that blood lead levels are a direct measure of worker health which is what one is trying to protect; therefore use of a standard based on blood lead will provide more certain protection, and will provide industry with the flexibility it needs to provide this protection in the most efficient way. OSHA rejected this approach in 1978 for a number of reasons:[3]

> o Air measurements will help locate sources of contamination and lead to control of emissions at the source and this is the preferred method of control.
>
> o The broad variability of worker blood lead levels make it difficult to pick an appropriate value that could be the basis for a citation. High blood levels can result either from high air levels or from moderate air levels and individual variability.
>
> o "Worker groups uniformly and vehemently oppose biological monitoring for compliance purposes. OSHA views this opposition seriously since workers would be the subjects of a compliance program based upon biological monitoring and their voluntary participation in such an invasive process would be crucial to its success."
>
> o "OSHA is concerned that a biological standard could impact negatively on workers with high blood leads and extended job tenure. Employers might terminate employment of those individuals to avoid citations...."

The district court of appeals endorsed these conclusions, particularly the last point. (Perhaps even more salient would have been the arguments that blood lead levels do not, in fact, measure worker health, and that a biological standard would be administratively burdensome.) The Supreme Court on June 29, 1981 refused to hear challenges to the Court of Appeals decision and the regulation finally took effect.

Other legal proceedings have concerned three matters: the remaining industries for which it was determined that OSHA had not demonstrated feasibility for compliance by means of engineering controls, the scheduled trigger levels for the Medical Removal Provision for which the lead industry collectively and in the case of many firms individually applied for delays, and announcements by OSHA that it planned to reconsider the technical and economic feasibility of many of the provisions of the standard, including the PEL.

For many of the remaining industries, on the last day of the Carter administration (January 19,1981), OSHA issued a revised finding of feasibility. However, this was immediately withdrawn for reconsideration by the incoming Reagan administration. On Dec. 11, 1981, OSHA finally issued revised estimates of feasibility for compliance for these remand industries and ordered compliance with the standard except for a two and one half year stay of the requirement that the PEL be met by engineering controls. Some other changes were made at this time as well--notably a clarification that "feasibility" would be defined on an individual employer basis*.

With respect to the Medical Removal triggers (Table 2.8), OSHA declined to grant industry-wide delays (except for a few one-month delays). However, OSHA has granted a large number of firms variances and interim orders delaying the third year MRP triggers. These were to expire February 28, 1983, at which time the fifth year MRP triggers were scheduled to come into effect. Collective and individual administrative applications have been filed by the lead industry seeking relief from those trigger levels. It should be noted that because the stays have been granted only to some firms, and because the timing has been different for different firms, the interpretation of data on MRP compliance up through 1982 and the effects of MRP is difficult, particularly in cases where what is available is only aggregated data from an unspecified partial subset of firms. Recently OSHA has granted a series of interim orders providing some firms with relief from scheduled implementation of the 6-month-average 50 ug/100g removal level, although the terms of these orders are in all cases stringent enough to require removal of workers at 60 ug/100g.

---

*The exact wording places the burden of proof to show that specific controls are not feasible on the employer:

> Where any employee is exposed to lead above the permissible exposure limit for more than 30 days per year, the employer shall implement engineering and work practice controls...except to the extent that the employer can demonstrate that such controls are not feasible. Wherever the engineering and work practice controls which can be instituted are not sufficient to reduce employee exposure to or below the permissible exposure limit, the employer shall nonetheless use them to reduce exposures to the lowest feasible level....

OSHA's announcement that it was soliciting comments about possible revisions to the lead standard as part of the Reagan administration program of regulatory reform has generated further public controversy. The issues OSHA stated it was considering were the feasibility of the PEL and the possibility of using less stringent alternatives, whether workers with only intermittent exposure to lead should be subject to the same standard, whether the MRP triggers are feasible, whether the pottery industry should be treated differently because of differences in the solubility of the lead (and thus possible differences in the rate of absorption, particularly if ingestion was important), and whether cost/benefit analysis should be included in the rulemaking procedure. To date, OSHA has exempted employers whose workers are exposed to lead fewer than thirty days per year from the requirement to achieve a 50 ug/m^3 PEL by engineering controls (although they must still achieve 200ug/m^3). There was discussion of a draft proposal[19] with a less stringent PEL (150 ug/m^3) to be achieved by engineering controls, as well as further delays in the deadlines for compliance with that level by engineering means, but this now appears not likely to be pursued.

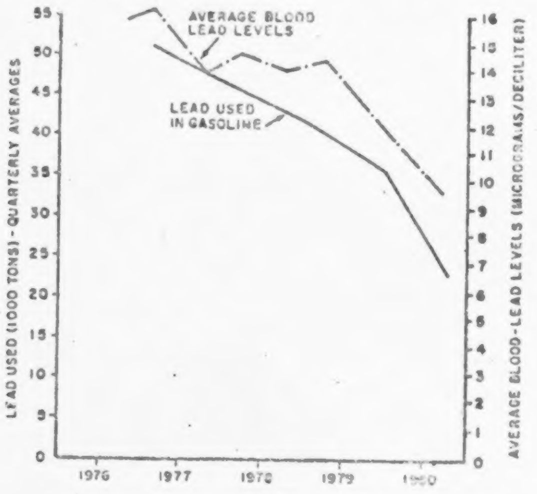
2.6 Changes in Environmental Exposure to Lead

Lead in the general environment is absorbed by people from the same pathways, inhalation and ingestion, that are illustrated in Figure 1.1. Lead finds its way into food from the airborne particulates, soil, and from solder in cans; it occurs in drinking water either from lead plumbing or from lead discharged into the water supply; it occurs in air on a broad scale from the burning of leaded gasoline, and in certain areas from emissions from industrial lead processes. Children also ingest lead from lead contaminated dust, gasoline emissions, and peeling lead paint.

Recently results have appeared from a sampling of blood lead levels from about 10,000 people during the years 1976-1980, as part of the second National Health and Nutrition Examination Survey (NHANES II) conducted by the National Center for Health Statistics.[20] The survey was intended to be representative of the U.S. population as a whole, and provides the first national estimates of blood lead levels for the general population. Because the sampling extended over four years, the survey also provides a measure of the changes occurring in the average blood levels of the population. The results are quite striking. Average blood levels have declined 35-37% over the four year period, from about 15.2 ug/100g of blood to about 9.4 ug/100g. The decline has closely matched the reduction in the use of lead in gasoline, suggesting that lead in air, from gasoline emissions, is responsible for more than half of the lead in the blood of the average American. The detailed dependence of the data on time, and the persistence of the decline across all subgroups of the population, make the attribution to changes in lead in gasoline very strong.[21] The decline in average lead levels and in gasoline lead emmissions are shown in Figure 2.5.[19] (note that the units of blood lead level in this figure, as is common in environmental contexts is ug/dl which differs by about 5% from the ug/100g used in the occupational standard setting proceedings--1 ug/100g is about .95 ug/100 ml). A decline of 5 ug/100g is a substantial fraction of the declines seen in blood lead levels in occupationally-exposed populations. We will discuss this in more detail in Section 3.4 below.

Figure 2.5*

Lead used in gasoline production and average NHANES II blood-lead levels, February 1976-February 1980



* Source: Morbidity and Mortality Weekly Report, Center for Disease Control, March 19, 1983, Vol. 31, No. 10

References for Section 2

1. Nriagu, Jerome O., Lead and Lead Poisoning in Antiquity John Wiley and Sons, New York, 1983, pp. 309-415

2. National Institute for Occupational Safety and Health, Criteria for a Recommended Standard...Occupational Exposure to Inorganic Lead, Revised Criteria-1978, DHEW publication #78-158, (1978): XII-2

3. 43 Federal Register, 54354 et seq., Nov. 21, 1978

4. 43 Federal Register, 46246 et seq., Oct. 5, 1978

5. National Academy of Sciences, Lead in the Human Environment (A Report of the Committee on Lead in the Environment, Environmental Studies Board, Commission on Natural Resources, National Research Council). Washington, D.C.(1980)

6. V. Batuman, et al. "Contribution of Lead to Hypertension with Renal Imapairment," New England Journal of Medicine 309, (1983) 17-21

7. Environmental Protection Agency, Air Quality Criteria for Lead, EPA-600:8-77-017, U.S. Government Printing Office, Washington, D.C., December 1977

8. H.L. Needleman et al., "Deficits in Psychologic and Classroom Performance of Children with Elevated Dentine Lead Levels," New England Journal of Medicine 300, (1979), 689-95

9. World Health Organization, Occupational Exposure to Lead and Arsenic, Geneva (1980), 50-53

10. Rabinowitz, M.B. et al., "Kinetic Analysis of Lead Metabolism in Healthy Humans," J. Clinical Investigation, V. 58 (1976):260

11. Bernard, S.R. "Dosimetric Data and Metabolic Model for Lead," Health Physics 32, (1977), 44

12. N.A. Ashford, R.D. Gecht, D.B. Hattis, and J.I. Katz, "The Effects of OSHA Medical Removal Protection on Labor Costs of Selected Lead Industries," M.I.T. Center for Policy Alternatives, Report # CPA-77-11, December 1977, and Federal Register 54453-6, November 21, 1978

13. Hattis D., Heaton G.R., Richardon B.E., Ballew M.A., Priest W.C., and Ashford N.A., "Environmental Regulation of Lead-- New Developments Since the Mid-1970's" MIT Center for Policy Alternatives, publication # CPA/WP-82-5, October 15, 1982, p. 3-5

14. reference 13, p. 1-7.

15. Occupational Safety and Health Act, section 6(b) (5), Occupational Safety and Health Reporter, Bureau of National Affairs, 71:1103

16. Occupational Safety and Health Act, section 3 (9), ibid p. 71:1102

17. National Instute for Safety and Health, Criteria for a Recommended Standard...Occupational Exposure to Lead U.S. Dept. Health, Education and Welfare, HSM 73-11010, 1972

18. Occupational Safety and Health Reporter, Bureau of National Affairs, Reference file, 31, p. 8421-51, (1982)

19. Occupational Safety and Health Reporter, Bureau of National Affairs, April 7, 1983, p. 941-2

20. Annest, J.L. et al.: "Blood Lead Levels for Persons 6 months-74 Years of Age: United States, 1976-80" NCHS Advancedata # 79, May 12, 1982

21. Breton, T.R. and Janney, A.M. "The Relationship Between Gasoline Lead Usage and Blood Lead Levels in Americans: A Statistical Analysis of the NHANES II Data", Report by ICF Inc. to the U.S. EPA, December 1982

3. ANALYSIS OF INFORMATION SUBMITTED TO THE OSHA HEARING RECORD, THE CHARLES RIVER REPORT, AND CASE STUDY FIRMS

3.1 Overview of Information and Conclusions

As indicated in Section 2 above, OSHA regulation of occupational lead exposure has been been the subject of continuous public discussion for at least six years. In the various proceedings*, a massive written record has been accumulated. This section reviews some of the information that has collected in the record since 1980 related to three questions:

- o How have air lead levels changed over time?
- o How have blood lead levels changed over time, and how do these changes compare with what was expected at the time of the promulgation of the lead standard?
- o What has been done to bring about these changes, and what might be done to make further progress in the future?

The single most helpful source of recent information for these purposes is a study done for OSHA by Charles River Associates and submitted in September, 1982[1]. Charles River conducted a survey of blood lead levels, air levels, and estimated costs for control measures required to attempt to meet current the OSHA standard in the future.

---

*Beginning with the hearings conducted before the promulgation of the standard, through the process of judicial review, applications to OSHA for general industry-wide stays of the provisions for Medical Removal Protection and the use of engineering controls, applications for individual company variances on these same issues, and the overall reconsideration of the standard by OSHA in the past two years.

(A copy of their questionnaire for environmental and blood level information is included as Appendix A.) We have their summary results, and the results from some (but not all) questionnaires for that survey (some companies said that their responses included confidential information and OSHA did not release those questionnaires into the public record). The information available gives us a relatively complete picture of what is going on in the primary smelting industry--where all 6 plants are covered in aggregated information and only one individual company questionnaire is missing--but we have much less complete and possibly unrepresentative information for secondary smelting and battery industries.

In addition to this industry-wide information, we visited one plant in the primary smelting industry, two plants in the secondary smelting industry (including the innovative Bergsoe secondary smelter in St. Helens, Oregon), and one battery plant. For one firm with several secondary smelting and battery plants, we obtained detailed information on air lead and worker blood lead distributions over time.

Below, section 3.2 will summarize information on what has happened to air lead levels and 3.3 will do the same for blood lead levels. Section 3.4 then analyzes the blood lead changes in terms of the air lead reduction and other factors. Section 3.5 then summarizes data on the dynamics of MRP program and makes some limited projections of future costs. Finally, in Section 3.6 we analyse the overall costs and likely exposure reduction benefits of future engineering and work practice controls, and discuss the potential of new production technology to contribute to additional reductions in exposure.

3.2 Recent Changes in Air Lead Levels

Table 3.1 presents summary data from the recent Charles River report on the observed distributions of air lead levels in 1981 or 1982 for workers in the primary smelting, secondary smelting, and battery industries. Table 3.2 compares current air lead exposures with those prevailing in these industries in about 1977, prior to the promulgation of the OSHA standard.

For later comparisons with what has happened to blood lead levels, it is helpful at this point to calculate approximate overall average air level reductions. Unfortunately, this is not an entirely straightforward exercise from the distributional data as shown in Tables 3.1 and 3.2. The major difficulty is in arriving at a reasonable estimate of average air levels for those workers listed as "over 200 ug/m^3". For primary and secondary smelting, the best source of information on this is some

Table 3.1
Recent (1981-2) Distributions of Air Lead Levels

(Numbers represent the percentages of workers monitored found to have exposures in various air lead level ranges.)

Industry/Plants Contributing Data	Air Lead Level (ug/m^3) Under 30	30-50	50-100	100-150	150-200	200+
Primary Smelting (6/6 plants, 2790 workers monitored)	11.3	9.1	15.2	12.8	6.7	44.9
Secondary Smelting (Data from 1799 workers in 22 plants in an industry reported to have 3700 production workers in 65 establishments in 1977)[2] (Data do not include "remelters/recyclers")	24.5 (under 50)		12.8	12.7	9.9	39.9
"Remelters/Recyclers" (as distinguished from other secondary smelters by Charles River) (7 plants with 612 "lead exposed" out of 2033 total workers)	10.0	21.2	24.0	19.3	11.4	14.1
Battery Manufacture (Data from 67 plants --including 14 making industrial batteries and the rest SLI in an industry with 266 establishments in 1977)[2] (Measurements covered 8,936 lead exposed workers out of 14,893 total workers in the covered plants-- there were about 36,500 total employees in the industry in 1980[3])	33.8	25.7	21.9	8.8	4.4	5.4

Source: Charles River, Tables 4.1, 4.5, 4.7, and 4.10 of Reference 1

TABLE 3.2

AIR LEAD EXPOSURES, BEFORE AND AFTER PROMULGATION OF THE OSHA LEAD STANDARD[a]

Industry		Total # of lead exposed workers	# contributing data to air lead distribution	Estimated Percentages of Exposed Workers in Various Air-Lead Ranges[b]		
				under 100	100-200	over 200
primary lead smelting	1977	2,200		18.0	21.0	61.0
	1981-82		2,790	35.6	19.5	44.9
secondary lead smelting	1977	3,170		21.0	12.0	67.0
	1981-82		1,799	37.3	22.6	39.9
storage battery manufacture	1977	16,700		57.0	23.0	21.0
	1981-82		8,936	81.4	13.2	5.4

a) Sources: based on information in Ashford, N.A., Gecht, R.D., Hattis, D.B. and Katz, J.I. *The Effects of OSHA Medical Removal Protection on Labor Costs of Selected Lead Industries* CPA-77/11 December 1, 1977 and Charles River Associates, *Economic and Environmental Analysis of the Current OSHA Lead Standard* (submitted to OSHA, 1982).

b) All air-lead levels are in micrograms per cubic meter detailed data presented by Charles River for two plants in each of these industries. (Caveat: it is not entirely clear that these plants are representative.) Averaging the air exposures for worker categories with average TWA exposures over 200 ug/m^3 yields the following:

	Total Workers in Plant	No. Workers over 200 ug/m^3 (% Total)	Average Air Exposures for Workers in Over 200 Categories (ug/m^3)
Primary Smelter No. 1	489	169 (35%)	990
Primary Smelter No. 2	200	115 (58%)	1,340
Secondary Smelter No. 1	56	42 (75%)	340
Secondary Smelter No. 2	32	24 (75%)	430

Thus it appears that the "over 200" category includes a great deal more exposure in the primary smelting industry than it does in secondary smelting. Exposures are particularly intense in the sintering and blast furnace areas of primary smelters, where exposures in the two studied plants averaged between 750 and 1800 ug/m^3 (see Section 3.6 below). For purposes of computing rough average total exposures in these industries, we will assume average values of 1,150 and 385 ug/m^3 respectively (these are the approximate averages for the two plants whose data is shown above).

The battery industry is an easier case, in that there are relatively few workers over 200 ug/m^3. Also, as a result of our case study work, we were provided with fairly detailed information on the distribution of air lead measurements over time in seven battery plants belonging to one firm:

	Air Levels (ug/m3)					Total No.
Time Period	under 50	50-99	100-149	150-199	200+	Samples
1978	31%	19%	13%	8%	29%	1,120
6/81-6/82	50%	23%	11%	5%	11%	5,783

When plotted on log-probability paper, both of these distributions appear to be very good straight lines (indicating the distributions are log-normal) and average air lead levels for battery workers over 200 ug/m^3 can be estimated at about 450 ug/m^3 for the 1978 period and about 340 ug/m^3 for the 1981-2 period. In both cases, the "under 50" category can be assigned an approximate average value of 25 ug/m^3

Based on the distribution data in Table 3.2 and the average values for levels over 200 ug/m^3 and under 50 ug/m^3 derived above, Table 3.3 presents our rough estimates of approximate average air exposures in the three industries and percentage reductions since 1977. For comparison, we also show average air levels for 1978 and 1981-2 derived from detailed data on seven plants belonging to our case study firm:

Table 3.3

	Approximate Average Air Exposure Level 1977	1981-2	Approximate % Reduction
Primary Smelting	740	565	24
Secondary Smelting	285	205	28
Battery Mfgr	160	80	50
	1978	1981-2	
Seven battery plants in case study firm	160	90	50

The estimates in this table of the percentage reduction in average ambient air levels for the primary and secondary smelting industry probably are understated, because for those industries we have used the same average value for the "over 200" category in both time periods. (It would be expected that the reductions in the numbers of workers over 200 would be accompanied by some reductions in the average exposures of those over 200, *but we have no good data on which to base estimates of this effect*). If we had treated the battery industry data in the same way (with "over 200" average air levels set at 400 ug/m^3 for both periods) the calculated percentage reduction would not have been greatly different from that shown (44%).

It is clear that progress has been made in reducing air lead levels--particularly in the battery industry--but current performance in all of the industries is far from the ultimate goal of compliance with a 50 ug/m^3 air standard with engineering controls alone. The primary and secondary smelting industries even have some distance to go yet before achieving engineering compliance with the old pre-1977 PEL of 200 ug/m^3.

OSHA industrial hygiene standards are *maximum permissible* levels, generally measured over a single day (8 hours) of exposure. There is no generally recognized definition of exactly what proportion of the time a given worker or workplace must be kept below the standard in order to be considered to be "in compliance" (theoretically, even a single day's exposure above the PEL for a single worker constitutes a violation--but whether an OSHA inspector would cite an employer if one out of a hundred industrial hygiene measurements were somewhat above a PEL is open to question.) For our purposes here, if we treat "compliance" with a standard as a reduction in air exposures to the point where no more than

5% of industrial hygiene measurements will be found to be over the standard on a given day, then as a rule of thumb, average exposure levels will usually need to be reduced to below 1/2 the maximum daily level permitted by the standard. (This is the general rationale used by NIOSH in setting action levels for monitoring at 1/2 of the PEL for toxic substances.)[22, 23] The operation of the same rule can be seen from the example of the battery industry, where with an average air level of about 80 ug/m^3, there are still somewhat more than 5% of overall industry measurements above 200 ug/m^3. Referring back to the approximate current average air exposures in Table 3.3 above, this implies that engineering compliance with a 50 ug/m^3 air standard would probably require at least a further three-fold reduction in average air levels for the battery industry, and considerably greater reductions from current levels for the primary and secondary smelting industries.

3.3 Recent Changes in Blood Lead Levels

Table 3.4 summarizes recent blood lead levels reported in the various industries. The upper part of Table 3.5 compares the recent blood lead data with the blood lead distributions thought to be present in these industries in about 1977 before the promulgation of the OSHA standard (from information presented in hearings). It should be noted that we are presenting the numbers as in units of ug/100g whereas the Charles River Report quotes their blood lead survey data in units of ug/100 ml. The actual survey form used by Charles River (Appendix A) does not specify whether the data should be reported in ug/100g or ug/100 ml., and in looking through the actual questionaires, the overwhelming number of firms who record what units they are using specify that their numbers are in ug/100g. The MRP regulations, of course, specify ug/100g.

It is clear that there has been considerable progress in reducing worker blood lead levels in all three industries. The numbers of workers over 60 ug/100g at any one time have been reduced between three and ten fold in these industries--from about 7,000 in 1977 to about 700 in 1981. The numbers of workers over 40 ug/100g in the three industries has been reduced from about 17,000 in 1977 to about 12,500 (neglecting changes in the total numbers employed in the industries). Finally, whereas before the standard there used to be an appreciable number (a few percent) of workers over 80 at any one time, such blood lead levels are now practically unknown. Particularly in view of the substantial reductions in the numbers of workers over 60 and over 80 ug/100g, it is likely that there have been major corresponding reductions in adverse health effects (See Table 2.1). We have been privately informed that appreciable

Table 3.4
Recent (1981-2) Distributions of Blood Lead Levels

(Numbers represent the percentages of workers monitored found to have blood lead levels in various ranges)

Industry/Plants Contributing Data	Blood Lead Level (ug/100g) Under 40	40-49	50-59	60-69	70-79	80+
Primary Smelting (7/7 plants*, 2470 workers monitored)	45.3	30.0	19.9	4.5	0.1	0.1
Secondary Smelting (Data from 1524 workers in 22 plants** (Data do not include "remelters/recyclers")	40.7	31.0	20.4	5.8	1.2	0.6
"Remelters/Recyclers" (as distinguished from other secondary smelters by Charles River) (7 plants with 612 "lead exposed" out of 2033 total workers in those plants)	60.3	26.0	11.3	1.6	0.8	--
Battery Manufacture (Data from 68 plants --including 15 making industrial batteries and the rest SLI*** (Measurements covered 8,622 lead exposed workers out of 14,886 total workers in the covered plants)	43.1	40.0	14.8	2.0	0.1	--

Source: Charles River, Tables 4.3, 4.5, 4.8, and 4.10 of Reference 1

Seven Battery Plants operated by one manufacturer interviewd by us.****	55	25	17	2	0.1	--

*Presumably including the ASARCO refinery.

**The secondary smelting industry is reported to have 36 plants and slightly over 3000 workers elsewhere in the Charles River report.

***Elsewhere the CRA reports a total of 136 plants in the battery industry.

****Data presented are averages for all measurements over the last two quarters of 1981 and the first two quarters of 1982, covering approximately 2000 workers.

TABLE 3.5

BLOOD-LEAD LEVELS OF EXPOSED WORKERS BEFORE AND AFTER PROMULGATION OF THE OSHA LEAD STANDARD[a]

INDUSTRY		Total # of lead exposed workers[d]	# of lead exposed workers in blood lead distribution	Estimated Percentages of Exposed Workers in Various Blood-Lead Ranges			
				under 40[b]	40-59	60-80	over 80
Primary lead smelting	1977	2,200		27.0	45.0	26.0	2.0
	1981-82		2,470	45.3	49.9	4.6	0.1
Secondary lead smelting	1977	3,170		29.0	30.0	25.0	16.0
	1981-82		1,524	40.7	51.4	7.0	0.6
Storage battery manufacture	1977	16,700		20.0	49.0	25.0	6.0
	1981-82		8,662	43.1	54.8	2.1	0

1978 PROJECTIONS OF THE LONG RUN IMPACT OF THE OSHA AIR LEAD STANDARD UPON WORKER BLOOD LEAD, FOR ALL LEAD INDUSTRIES[c]

	Under 40	40-50	50-60	Over 60ug/100g
Compliance with a 200 ug/m^3 air lead standard (average = 100ug/m^3)	16	29	33	22
Compliance with a 100 ug/m^{3}air lead standard (average = 50 ug/m^3)	49	34	14	2.6
Compliance with a 50 ug/m^3 air lead standard (average = 25 ug/m^3)	71	23	5.5	0.5

---

[a] Summarized from 43 Federal Register 54453-6, November 21, 1978, and Charles River Associates, Economic and Environmental Analysis of the Current OSHA Lead Standard (submitted to OSHA, 1982).

[b] All blood-lead levels are in micrograms per 100g.

[c] From Ashford, N.A., Mendez, W. and Hattis, D. Analysis of Available Evidence on Blood Lead-Air Lead Relationships Relevant to the Selection of Permissible Exposure Limit for Lead in Air, July 1978, CPA-78-13.

[d] Data on total number of exposed workers in 1977 from Ashford, N.A., Gecht, R.D., Hattis, D.B., Katz, J.I. The Effects of OSHA Medical Removal Protection on Labor Costs of Selected Lead Industries. CPA-77/11 December 1, 1977.

improvement has been noted during the implementation of the standard ingroups of workers studied for nerve conduction velocity[20], however these data are not yet published and available for detailed examination.

The lower part of Table 3.5 and Table 3.6 provide some further comparisons. The lower part of Table 3.5 shows the blood lead distributions that were expected to result in the very long run from compliance with alternative air standards (with average exposures at half the maximum permissible levels), based on the air-lead/blood lead relationship used by OSHA during the standard-setting process. (Less improvement would be expected than this in the first few years after compliance, because current blood lead levels reflect some contribution from the accumulated lead stored in the bones of workers over many years of relatively high previous exposure.) It appears that the current bloodlead distribution in the battery industry is similar to what one might expect from long-run engineering compliance with an air standard of 100 ug/m^3 (that is, average effective air levels of 50 ug/m^3). The primary and secondary smelting industries are not yet at this stage; they are between what one would expect with 100 ug/m^3 and 200 ug/m^3 compliance levels. But they appear to be closer to the point associated with 100 ug/m^3 compliance than with the distribution which would reflect compliance with 200 ug/m^3.

Table 3.6 shows some projections made in 1978 of the expected fall in worker blood lead levels over time, for compliance with maximum permissible exposure levels of 50 and 100 ug/m^3, assuming:

o The dynamic model of lead transfer in the body (and other simulation assumptions) developed for OSHA during the standard-setting process[4,5]

o The starting distributions of blood lead levels shown in Table 3.5 for 1977

Table 3.6
1978 Projections of The Fall in Blood Lead Levels
After Promulgation of the OSHA Lead Standard

Industry	Compliance Level (ug/m^3)	Time After Compliance	Blood Lead Level (ug/100g)			
			Under 40	40-59	60-79	Over 80
Primary Smelting	50	2 months	36	51	13	.1
		1 year	44	50	6	--
		3 years	56	42	2.2	--
		5 years	61	37	2.1	--
		10 years	68	31	1.0	--
	100	2 months	24	55	21	.5
		1 year	27	57	15	.5
		3 years	34	57	10	--
		5 years	36	57	7	--
		10 years	49	52	6	--
Actual, 1981-2		about 2.5 years	45	50	4.6	.6
Secondary Smelting	50	2 months	38	43	19	.6
		1 year	46	45	9	.2
		3 years	57	39	3.5	--
		5 years	61	38	1.7	--
		10 years	66	32	2.0	--
	100	2 months	26	51	23	.6
		1 year	33	49	18	.5
		3 years	34	55	11	--
		5 years	38	55	8	.1
		10 years	42	52	6	--
Actual, 1981-2		about 2.5 years	41	51	7	
Battery Mfgr	50	2 months	40	46	14	.4
		1 year	49	46	6	--
		3 years	62	36	2.1	--
		5 years	68	31	1.2	--
		10 years	73	26	1.1	--
	100	2 months	29	50	21	.6
		1 year	35	49	15	.3
		3 years	40	55	6	--
		5 years	43	51	6	--
		10 years	49	47	4.5	--
Actual, 1981-2		about 2.5 years	43	55	2.1	--

Source of Projections: Mendez, et al., reference 6 o Implementation of an 80-60 medical removal/return system in the first year after promulgation of the lead standard, followed by a 70-50 program in the second year, a 60-40 program beginning in the third year, supplemented with a program of removal after 3 successive blood lead measurements greater than 50 starting in year 5, and

o Exposures of individual workers in the industries distributed uniformly over the range from 10-50 ug/m^3 for the 50 ug/m^3 compliance level, and in more complex fashion for the 100 ug/m^3 compliance level (exposures at 10-50 for some worker groups and at 50-100 for others, in varying proportions in different industries). These exposure reductions were assumed to begin in year 1 of standard promulgation, achieved at first by respirators, but later primarily by engineering controls.

With the legal uncertainties arising from the challenge to the lead standard, the Charles River data for 1981-2 probably should be considered to represent a point about 2 and one half years after the beginning of implementation of the lead standard. The first stage of the MRP requirement went into effect in March, 1979. Even then there was some residual uncrtainty as litigation did not end until the Supreme Court denied certiorari in June, 1981.

Focusing on the one- and three-year time points after projected implementation in Table 3.6, it appears that the blood lead performance of the primary smelting industry is not too far from the performance that was expected for compliance with an effective worker exposure limit of 50 ug/m^3, although the full improvement anticipated by 3 years after promulgation has not quite been achieved. The record appears closer to the expectations under a 50 standard than the expectations under a 100 ug/m^3 effective exposure. This also seems to be generally the case for the secondary smelting and battery industries, although as we said before, the conclusion must be more reserved because of the incompleteness of our information. In summary, the best evidence available suggests that the blood lead performance in the three industries has approached, but not quite met, the expectations of OSHA prior to the standard. Below we will discuss the possible reasons for this behavior of blood lead levels.

3.4 Interpretation of Blood Lead Level Changes in Terms of Air Lead Levels, General Population Lead Exposure Changes, and Other Control Measures

We must attach a serious caveat to the straightforward comparison made in the previous section. It seems likely that some portion of the blood lead reductions observed for lead workers must be attributed to the reduction of non-occupational exposures to lead for the general U.S. population.

Based on an extensive random sample of the U.S. population, average adult blood lead levels declined about 36% (from 15.2 ug/100g to 9.7 ug/100g) over the four year period from 1976 to 1980[7-8]. This decline is similar in magnitude and timing to the decline in the use of lead in gasoline (See Figure 2.5, page 2-22). Recent statistical analyses of the detailed data in different locations and for various population subgroups appear to confirm that most of the reduction is likely to be attributable to this source of exposure[9] (although there may also have been some contribution from reduction of dietary lead from "tin" cans and from reduction of drinking water lead).

If we use the data in Tables 3.4 and 3.5 to calculate very approximate average blood lead levels in the three industries surveyed in the CRA report and the information separately obtained on a group of seven battery plants owned by one manufacturer, we obtain the following:

Table 3.7

Approximate Average Blood Lead Levels

Industry	1977	1981-2	Difference
Primary Smelting	49.4	41.6	7.8
Secondary Smelting	56.5	44.2	12.3
SLI Battery Manufacture	53.2	42.4	10.8
	1978	1981-2	
Seven Battery Plants	53.0	38.3	14.7

These averages were computed by (1) plotting the blood lead distributions for each industry on log-probability paper, (2) drawing straight lines between the points, and (3) averaging the blood lead levels for the 10th, 30th, 50th, 70th, and 90th percentiles of the distributions. To check these calculations, we tried other methods of interpolation. The differences between average 1977 and 1981-2 blood lead levels are not sensitive to the interpolation method; the individual average blood lead levels in specific years vary +/- 2 ug/100g.

To say the least, it is not obvious that one can neglect the 5 ug/100g decline in general population blood lead levels between 1976 and 1980 as one component of the 8-15 ug/100g average decline in worker blood lead levels in these industries. Exactly how much of the decline in worker levels should be attributed to the decline in non-occupational exposures is likely to be controversial, however. Under the pharmacokinetic model used by OSHA, long term blood lead levels are a simple linear function of long term average lead intake into the bloodstream*. If this is correct, then the blood lead levels produced by different sources of exposure should be simply additive, and therefore nearly half of the worker blood lead reduction would have to be attributed to the reduction of non-occupational sources of exposure. On the other hand, if the true relationship between lead absorption and blood lead level were to be highly non-linear, as was suggested by some of the the industrial parties to the lead hearings, a greater proportion of the decline in worker blood lead levels should be attributed to reductions of workplace exposures**.

---

*Particles of different sizes, however, can be absorbed at greatly different efficiency (37% or more for "small" particles in the under .5 micron size range typical of ambient air exposures from gasoline-derived lead vs. 10% or less for dietary lead or most air lead from occupational exposures--based on original data from Kehoe[22,23]). This difference is relatively well accepted in the literature. In the OSHA model, the differential absorption efficiency of particles of different size was the main mechanism postulated to explain the apparent non-linearity in air-lead/blood lead relationships. Larger particles tend to settle out of the air faster than smaller particles. Therefore workers exposed to higher air lead levels (being, on average, closer to sources of emission) may tend to be exposed to a larger proportion of larger particles.

**Chamberlain[21] has reviewed some recent evidence for non-linearity in the relationship between urinary lead excretion and blood lead level. It is possible that the rate of urinary excretion of lead at average occupational blood lead levels (40-50 ug/100g) may be as much as twice what it might be expected to be under a simple linear projection from urinary lead excretion at 10-15 ug/100g. This would be expected to produce some non-linearity in the relationship between lead absorption and blood lead level, of a size that depends on one's assumptions about the magnitude of exchange between blood and long term lead storage compartments (see Figure 2.2). Assuming the exchange rates shown in Figure 2.2, the 5-6 ug/100g reduction in average environmentally-dependent blood lead levels would be expected to translate into about a 4-5 ug/100g reduction in occupational blood lead levels. If the blood lead/long term storage transfer rate is only half that shown in Figure 2.2, the 5-6 ug/100g environmental change would be expected to produce approximately a 3-4 ug/100g reduction in blood lead levels.

We have attempted to relate the observed decline in blood lead levels to the decline in air lead levels using the following assumptions:

1) the average blood lead levels of the adult U.S. population (15.2 ug/100g in 1976 and 9.7 ug/100g in 1980) roughly reflect the average environmental background blood lead levels for the workers in our three lead industries at the ends of our two observational periods (1977 and 1981-2)

2) the OSHA dynamic model which (a) produces changes in blood lead levels which are directly proportional to total lead absorption to the bloodstream (that is, no non-linearities in absorption or excretion); and (b) indicates that most of the ultimate blood lead response to a change in lead intake should occur within the first year or two (see Fig. 2.1),

3) the OSHA assumptions about particle size effects, which amount to assuming that roughly the first 12.7 ug/100g of blood lead level over the environmental background results from the first 12.5 ug/m^3 of occupational air exposure (assumed to be in fine particles absorbed via the lung with about 37% efficiency).

The results of calculations based on these assumptions are shown in Table 3.8 which relates 1977/81-2 changes in the average occupational increment in blood lead level in these industries to changes in the potential absorption of lead from air, under the OSHA's absorption efficiency and particle size assumptions without any correction for the action of respirators. Neglecting non-linearities, the "occupational increment" to blood lead level is calculated by subtracting the average general population adult blood lead levels in the two years (15.2 ug/100g in 1977 and 9.7 ug/100g in 1981-2). "Potential absorption" of lead in micrograms per day is calculated as

$$(9.6\ \text{m}^3\ \text{air intake})[(12.5\ \text{ug/m}^3)(.37) + (L - 12.5)(.08)]$$

where L is the total air lead level, and the first 12.5 ug/m^3 are assumed to be small particles absorbed with 37% efficiency. The potential absorption of lead attributable to large particles is calculated as

$$(9.6\ m^3\ \text{air intake})[(L-12.5)\text{ug/m}^3(.08)]$$

The increment of blood lead level attributable to large particle exposure is calculated on the assumption that the small particle portion of the air lead level (the first 12.5 ug/m^3) is actually absorbed at the assumed 37% efficiency, irrespective of the use of respirators. This gives an increment of 12.7 ug/100g to the occupational portion of the blood lead level which is subtracted to determine the increment attributable to large particle absorption.

If we assume that the reductions in lead absorption from occupational exposure (except for the fine particle component) are proportional to the reduction in corrected air level, it is clear from Table 3.8 that the observed reductions in air lead levels along with the changes in environmental exposure are ample to explain the reduction in blood lead levels*. The margin is such that this would still be true even if the non-linearities in lead excretion suggested by Chamberlain were taken into account (to see this, simply subtract 1-2 additional ug/100g from the 1981-2 blood lead levels attributable to occupational exposure in Table 3.8).

Without correcting for nonlinearities, the reduction in environmental background levels appears to account for about 40-50% of the overall reduction in average blood lead levels; with the nonlinearity correction, changes in environmental background appear to still amount to at least 30% of the average reduction. Of course, if one focuses on the minority

---

*We would have had to adopt a very different view if we had not taken cognizance of the changes in environmental background.

Table 3.8
Reductions in Air Lead Levels and Blood Lead Levels Taking Account of Changes in Environmental Exposure and Nonlinearities Attributable to Particle Size Effects

	1977	1981-2	Reduction
Primary Smelting			
Average Air Lead (ug/m^3)	740	565	
Potential Occ. Absorption (ug/day)	603	469	
Potential Occ. Absorpt. from Large Particles Only (ug/day)	559	424	24%
Average Blood Lead (ug/100g)	49.4	41.6	
Occ. Increment to Blood Lead (ug/100g)	34.2	31.9	
Estimated Increment to Blood Lead From Large particles (ug/100g)	21.5	19.2	11%
Secondary Smelting			
Average Air Lead (ug/m^3)	285	205	
Potential Occ. Absorption (ug/day)	254	192	
Potential Occ. Absorpt. from Large Particles Only (ug/day)	209	148	29%
Average Blood Lead (ug/100g)	56.5	44.2	
Occ. Increment to Blood Lead (ug/100g)	41.3	34.5	
Estimated Increment to Blood Lead From Large particles (ug/100g)	28.6	21.8	24%
Battery Manufacture			
Average Air Lead (ug/m^3)	160	80	
Potential Occ. Absorption (ug/day)	158	96	
Potential Occ. Absorpt. from Large Particles Only (ug/day)	113	52	54%
Average Blood Lead (ug/100g)	53.2	42.4	
Occ. Increment to Blood Lead (ug/100g)	38.0	32.7	
Estimated Increment to Blood Lead From Large particles (ug/100g)	25.3	20	21%
	1978	1981-2	
Seven Battery Plants			
Average Air Lead (ug/m^3)	180	90	
Potential Occ. Absorption (ug/day)	173	104	
Potential Occ. Absorpt. from Large Particles Only (ug/day)	129	60	53%
Average Blood Lead (ug/100g)	53	38.3	
Occ. Increment to Blood Lead (ug/100g)	37.8	28.9	
Estimated Increment to Blood Lead From Large particles (ug/100g)	25.1	15.9	37%

of workers at greatest risk for health damage (those who had particularly high blood lead levels prior to the standard--over 70 or 80 ug/100g), the blood level reductions attributable to the action of the OSHA standard have been much larger, and the contribution of environmental bacground reduction has been relatively smaller.

How reasonable is the assumption that the reduction in occupational dose is in fact proportional to the reduction in air levels? Figure 1.1 suggests that most of the lead absorbed by the worker is first emitted into the air, whether it is finally inhaled or picked up from a surface and ingested. If the controls instituted along the two pathways (Figure 1.2) have remained the same, then the proportionality assumption seems quite plausible. Most industry health managers believe that, in fact, the controls instituted, respirators, hygenic practices, etc. have been more rather than less effective in the last few years.

The data in Table 3.8 indicate that the percentage reductions in blood lead levels attributed to occupational exposure to large particles have in all industries been equal to or smaller than the reductions in estimated potential absorption from large particles. There are then three possible interpretations of this finding:

o Interpretation 1 The estimated percentage reductions in large particle air lead levels accurately represent the reduction in the dose attributable to large particles (with some small possible adjustment for non-linearities in excretion), and respirator and hygenic protection has not shown major improvements in the last three to four years.

o Interpretation 2 In addition to the reduction in air lead levels there has been a further reduction in worker lead absorption due to improved hygenic programs and greater care with respirators. The reductions in air lead did not in themselves lead to a proportionate reduction in exposure because those reductions were primarily in large particles of lead which are even less easily absorbed than is assumed in the OSHA model.

o Interpretation 3 In addition to the reduction in air lead levels there has been a further reduction in worker lead absorption due to improved hygenic programs and greater care with respirators. The reductions in air lead did not lead to a proportionate reduction in dose and the change in environmental absorption was not correctly estimated because the biology of lead absorption is more strongly non-linear than indicated by our calculations based on non-linearities of excretion.

In our opinion, interpretation 3 is less believable at present than the other interpretations because it is most likely that the absorption of lead takes place through passive transfer processes which are expected to be linear functions of lead concentration in the various body compartments[11]. A more detailed look at the dynamics of blood lead levels using existing data could shed more light on this question, and there are feasible experimental tests as well. In order to choose between interpretations 1 and 2, more data are needed on particle size distributions in lead plants than are presently available; in particular it would have been desirable to have before and after information on size distributions that now is not available. The study of particle size distributions and the details of lead absorption ought, in our view, to be of high priority in future research on occupational lead.

We can leave open the question of whether interpretation 1 or 2 is correct and find some interesting results by revising the analysis in section 3.3 to take into account the change in the environmental absorption of lead. We have calculated revised expected distributions of blood lead levels for the third year after compliance with the three compliance levels listed in Table 3.6, 50 ug/m^3, 100 ug/m^3, and 200 ug/m^3 assuming that the contribution from environmental exposure has decreased 5 ug/100g since 1977, and, as in Table 3.6, have compared them with the observed distributions for the three industries. The results are shown in Table 3.9.

Table 3.9
Projections of The Fall in Blood Lead Levels
Corrected for the Fall in Non-Occupational Exposures

Industry	Compliance Level (ug/m^3)	Time After Compliance	Blood Lead Level (ug/100 ml) Under 40	40-59	60-79	Over 80
Primary Smelting	50	3 years	75	26	--	
	100	3 years	50	44	6	--
	200	3 years	31	47	20.5	1.5
Actual, 1981-2		about 2.5 years	45	50	4.6	.6
Secondary Smelting	50	3 years	72	26	2	
	100	3 years	50	43	7	
	200	3 years	32	44	20	2
Actual, 1981-2		about 2.5 years	41	51	7	
Battery Mfgr	50	3 years	80	19	.8	
	100	3 years	57	41	2	
	200	3 years	35	47	16	2
Actual, 1981-2		about 2.5 years	43	55	2.1	--
Actual, 1981-2 Seven Battery Plants		about 2.5 years	56	42	2	--

It is clear that the distributions for all three industries are quite close to what might be expected for compliance with an effective maximum exposure level of 100 ug/m^3. Since the lead standard prescribed immediate compliance with an effective exposure level of 50 ug/m^3 through respirator use when engineering controls were not feasible, we must conclude that the lead industries are still significantly out of compliance with the standard, although there has been considerable progress from pre-1977 conditions.

We were only able to deduce the effective level of compliance because we had available blood lead distributions (and a model for their dependence on exposure). What could one expect for the use of respirators to lower exposure to other substances for which, however, there is no available biological indicator. The standard procedure is to measure air levels of the substance and to assume that respirators provide a protection factor, based on laboratory measurements. We can calculate an effective protection factor for the respirator use practices in each of the three industries by comparing their measured average air levels with the effective compliance level of 100 ug/m^3. As was done in the calculations of blood lead distributions, we assume that the effective compliance level of 100 ug/m^3 corresponds to an average air level of 50 ug/m^3. The results are shown in Table 3.10.

Table 3.10
Effective Protection Factors for Respirator Use in the Three Industries

Industry	Average Air Lead Level (ug/m^3)	Effective Air Lead Level (ug/m^3)	Protection Factor
Primary Smelting	585	50*	12
Secondary Smelting	205	50	4
Battery Manufacture	80-90	50	2

*Note: these average effective exposure levels of about 50 ug/m^3 correspond to approximate compliance with a maximum permitted exposure level of about 100 ug/m^3--see discussion in Section 3.2 (p. 3-8).

The protection factors vary considerably, from 2 X to 12 X reduction in exposure which may reflect differences in the size distributions of the particles in the different industries and/or differences in the quality and extent of respirator programs. All of the values are much lower than the factors 30 X to 1000 X which are claimed by manufacturers and testers of respirators based on laboratory measurements (where respirators are in fact worn and carefully fitted for the measurement), but the results correspond reasonably well with past field observations of average respirator protection factors for particulate exposures in actual use[19-20]. (Recent measurements with cadmium particles[20] have indicated an average effective protection factor of about 4; in an earlier study of workers exposed to coal dust[19], average effective protection factors for different groups of workers ranged between 3 and 9.) We believe that reliance on respirator use to meet specific goals in exposure reduction must be done with great caution in the light of these results, which represent, to our knowledge, the first industry-wide operational comparisons of air exposures with absorption.

One final question that might be asked in this section is whether, in view of the fact that the current blood lead distributions in Table 3.6 agree closely with OSHA's expections under compliance with the standard, rather than the expectations they would have had, (Table 3.9) had they known of the reduction in environmental lead, should industry still be required to comply with the 50 ug/m^3 PEL? According to OSHA's reasoning in setting the standard, the level was set based on feasibility, and not on the absence of expected health effects. It is clear from the kind of calculations seen in Table 3.9 that even with the lowered environmental background, appreciable numbers of workers can be expected to have blood levels that exceed 40 ug/100g with a PEL of 50 ug/m^3. Because this was the blood level considered necessary to adequately protect workers against material impairment, because 50 ug/m^3 was deemed feasible, and because the lowered environmental contribution has the effect of reducing MRP costs, the change in environmental background is not legally sufficient to justify changing the standard. It should be considered in any future examination of the feasibility of provisions of the standard, however.

3.5 Operation of the Medical Removal Protection System

As discussed in Section 2.5 above, one of the innovative features of OSHA's 1978 occupational lead exposure standard is the medical removal protection (MRP) program. The MRP regulations first took effect in March 1979.

The program provides for the monitoring of workers' blood lead levels on at least a quarterly basis (workers exposed above the permissible exposure limit and workers with blood lead levels over 40 ug/100g are supposed to be monitored monthly). At the outset, workers were placed on medical removal when their blood lead reached 80 ug/100g and returned to the job when their blood lead decreased to 60 ug/100g. The program was designed to have gradually decreasing "trigger" blood lead levels for removals and returns, with 70/50 and 60/40 trigger levels taking effect in the second and third years after the effective date of the regulation. The triggers dropped to 70/50 on March 1, 1980 and to 60/40 on September 1, 1981, except that many firms in the primary and secondary smelting and battery industries have been given extensions of the time for implementation of the 60/40 triggers.

As part of their work for OSHA, Charles River Associates surveyed the industries examined in this report for their experience with the MRP program (see Appendix A - question 10 addresses MRP issues). The questionnaire was sent to primary smelters, secondary smelters, remelters/recyclers, industrial battery manufacturers and starting, lighting and ignition (SLI) battery manufacturers in the U.S.

The MRP tables below and in Appendix C were compiled from the portion of the lead industry responses to the CRA questionnaire that were not considered confidential by the responding companies and OSHA. The MRP data from the primary smelters was fairly complete, but the availble response from the other lead industries was poor; only 6 out of about 36 secondary lead smelters and 8 out of about 136 battery plants. It is possible that the small groups of secondary smelters and battery plants that responded are not representative of the industries--perhaps the group that allowed use of their data contained a larger number of firms that were having problems with the MRP program (on the other hand, it could be that larger companies with better compliance and MRP experience are more heavily represented in the data). Also when only a few plants respond, a large company with complete MRP data could dominate the available statistics for the industry. Many of the plants that did respond did not complete all of the sections of the questionnaire; there was little information about air lead exposure, job classifications, wages and costs connected with MRP (the latter were held in confidence). For these reasons, the MRP data may be biased and the conclusions reached based on these tables must be viewed with caution.

Table 3.11 is a summary of the data on medical removal protection transfers for primary smelters, secondary smelters, and medium to large SLI and industrial battery plants. The remelters/recyclers were not included in this table because there was data from only two plants in that industry, and one of those supplied no information on the size of its lead-exposed workforce. No MRP data were included on any of the questionnaires from small SLI battery manufacturers. One can see from

TABLE 3.11

SUMMARY OF MEDICAL REMOVAL PROGRAM TRANSFERS, BY INDUSTRY

1979-1981*

	YEAR	# OF PLANTS	AVERAGE # OF LEAD EXPOSED WORKERS	AVERAGE # OF WORKERS ON MRP DURING YEAR	AVERAGE # OF WORKER YEARS ON MRP PER PLANT	PERCENT WORKERS EVER ON MRP DURING YEAR	PERCENT WORKTIME ON MRP TRANSFER DURING YEAR
Primary [a] Smelters	1979	5	465.0	20.8	4.68	4.5	1.0
	1980	5	418.6	31.4	8.92	7.5	2.1
	1981	5	492.4	17.8	6.31	3.6	1.3
Secondary [b] Smelters	1979	6	120.2	3.5	1.26	2.9	1.0
	1980	6	104.0	8.8	4.79	8.5	4.6
	1981	6	95.8	10.7	6.58	11.1	6.9
Battery Plants[c]	1979	8	175.5	2.1	0.72	1.2	.4
	1980	8	140.0	7.5	2.60	5.4	1.9
	1981	8	161.8	6.0	2.48	3.7	1.5

*Data obtained from the Charles River Associates questionnaire

[a] includes 5 primary smelters: 1008912, 1040372, 1129272, 1199994, 1100272 with a total of 2,129 workers on average over 1979-81

[b] includes 6 secondary smelters: 1086114, 1064018, 1132166, 1105012, 1008052 with a total of 640 workers on average over 1979-81

[c] includes 7 SLI battery plants:
4 large; 1181646, 1086514, 1184234, 1043162
3 medium; 1021468, 1168132, 1119614
and one industrial battery plant: 1021812 with a total of 1,273 workers on average over 1979-81

Table 3.11 that usually less than 10 percent of the lead exposed workforce is medically removed during a given year, and, at least in the primary smelting and battery industries, the percentage of total work time spent on MRP was 1-2%. For secondary smelting, however, there is some evidence of greater problems. For the six secondary smelters providing data, 11% of the lead-exposed workers were on MRP at some time during 1981, and nearly 7% of the plants' worktime was spent on MRP transfer.

For comparison, simulations done prior to the promulgation of the OSHA standard predicted the following percentages of total worktime on MRP (summing transfer and layoff time) in the three industries, given compliance with alternative maximum exposure levels[6]:

Industry	Year*	Percentage of Total Worktime on MRP Maximum Exposure = 50 ug/cubic m	 Maximum Exposure = 100 ug/cubic m
Primary Smelting	1	.2	.4
	2	.1	.9
	3	1.6	4.8
	4	.9	3.5
	5	.9	1.8
Secondary Smelting	1	.8	1.0
	2	.5	1.5
	3	2.1	5.0
	4	1.0	3.5
	5	1.2	3.2
Battery Industry	1	.4	.7
	2	.14	.9
	3	1.1	5.4
	4	1.3	4.6
	5	.7	3.5

*80/60 triggers to be implemented in the first year of the standard, 70/50 in the second, 60/40 in the third, and removal after three successive blood lead readings over 50 starting in year 5.

The total percentages of worktime on MRP would have been expected to be greater than this if more use were made of transfers rather than layoffs in the simulation, as seems to have been the case in practice. Also, the simulation was based on assumed exposures on transfer averaging only 10 ug/m^3 whereas as actually promulgated MRP workers may be tranferred to jobs with air lead levels as high as 30 ug/m^3 (averaging perhaps 15 ug/m^3). Another factor that would change the results in the opposite direction is the reduction in environmental background exposures, which should be expected to reduce removal durations, other things being equal. On balance, the results of this imperfect comparison seem reasonably consistent with the practical achievement of compliance with an effective maximum exposure level of 100 ug/m^3 in the first two years of MRP implementation in the primary smelting and battery industries, as we found earlier in the discussion of the fall in overall blood lead levels.

Table 3.12 summarizes the data on medical removal duration as a function of removal level in the major lead industries for the period 1979-1981. For the total of 501 medical removals the distribution of removal duration is roughly log-normal for removal times less than about 240 days (Figure 3.1) with a median of about 140 days (20 weeks).

There is some evidence, however, that there are somewhat more particularly long removals than would be expected from a strictly log-normal distribution. Overall, in the major lead industries, 59 out of 501 (12 percent) of the workers were on MRP more than 480 days. Table 3.13 lists information about the nine primary smelter employees that were on MRP more than 480 days. All of these arose in a single plant.

TABLE 3.12
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL

MAJOR LEAD INDUSTRIES*

REMOVALS BEGUN 1979-1981

Removal Level (ug/100g)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
60			1 (50%)			(50%)	2
60-69		4 (6%)	16 (23%)	29 (41%)	17 (24%)	5 (7%)	71
70-79	7 (3%)	25 (12%)	68 (32%)	68 (32%)	24 (11%)	21 (10%)	213
80-89	1 (1%)	21 (15%)	40 (29%)	42 (31%)	17 (13%)	15 (11%)	136
90-109	0	6 (9%)	27 (41%)	14 (21%)	6 ([illegible]%)	13 (20%)	66
110	0	1 (8%)	5 (38%)	0	3 (23%)	4 (31%)	13
TOTAL:	8 (2%)	57 (11%)	157 (31%)	153 (31%)	67 (13%)	59 (12%)	501

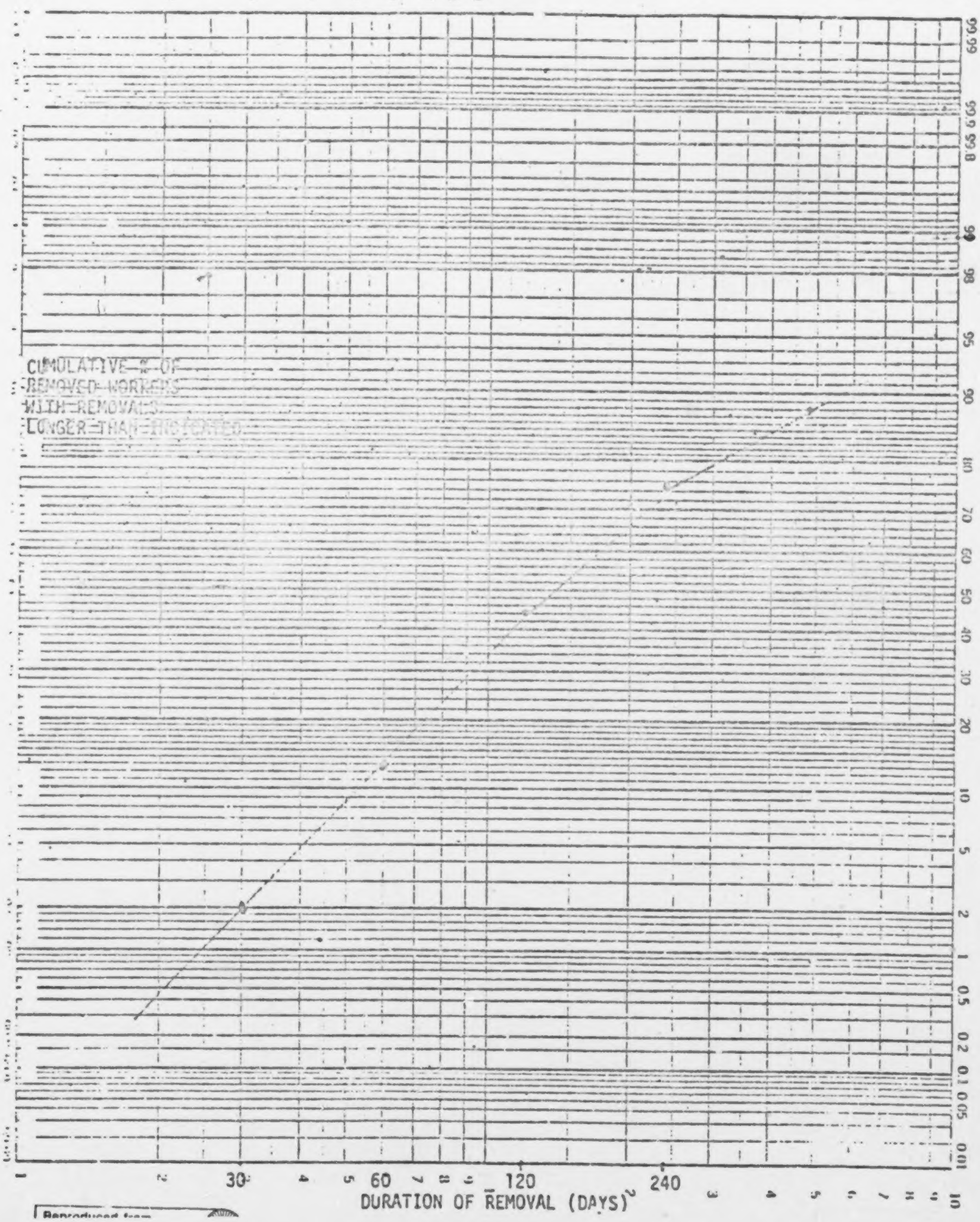
RETURNS FROM MRP

Return Level (ug/100g)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
40	1 (1%)	1 (1%)	24 (35%)	23 (33%)	17 (25%)	3 (4%)	69
40-49	1 (1%)	19 (12%)	67 (42%)	50 (31%)	14 (9%)	9 (6%)	160
50-60	3 (2%)	34 (19%)	63 (35%)	57 (32%)	16 (9%)	5 (3%)	178
Still on MRP	0	2 (3%)	1 (2%)	18 (27%)	18 (27%)	27 (41%)	66
Terminated**	3 (11%)	1 (4%)	2 (7%)	5 (18%)	2 (7%)	15 (53%)	28
TOTAL:	8 (2%)	57 (11%)	157 (31%)	153 (31%)	67 (13%)	59 (12%)	501

*Includes MRP data from primary smelters, secondary smelters, battery plants and remelters.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired [illegible]

FIGURE 3.1
DISTRIBUTION OF REMOVAL DURATIONS



Reproduced from

TABLE 3.13
NINE PRIMARY SMELTER EMPLOYEES ON MRP 480 DAYS OR MORE REMOVALS BEGUN 1979-1980

PLANT #	EMPLOYEE I.D. #	REMOVAL Pb-B	# OF DAYS ON MRP	STILL ON MRP?	TENURE (DAYS AFTER HIRE)
1100272	1963	91	1027	yes	1,268
1100272	7233	89	710	no	10,039
1100272	7247	74	746	yes	7,457
1100272	7410	80	731	yes	3,124
1100272	7383	80	575	yes	4,426
1100272	7216	73	568	yes	9,149
1100272	7066	76	556	yes	2,857
1100272	7980	78	554	yes	5,014
1100272	7232	85	647	yes	10,190

Some of their job tenures are quite long (although we have not made a rigorous comparison with workers with lesser removal times) and unfortunately, we have no information about exposure or job class for these individuals. At the time the latest data were collected (5/1/82), only one of these workers had been returned to his old job; the rest were still on medical removal. One person had been on MRP over 1,000 days (2.8 years).

Median removal times tended to be somewhat longer for individuals removed at the lowest levels:

Removal Level	No. Removals	Median Removal Time
60-69	71	175
70-79	213	130
80-89	136	135
90+	66	120

This may be partly because more of the people removed at relatively high blood lead levels may have been removed under the 80-60 removal/return triggers. It was not possible to ascertain for individual plants when the transitions to different removal regimes occured because of the complex pattern of variances in different plants. However, it is likely that the consequences of a gradual transition to lower removal and return triggers can be seen by comparing the 339 removals begun during 1979-80 with the 143 removals begun in 1981. For the earlier group, the median duration was about 130 days; for the later group, the median duration was slightly more than 160 days. If anything, this difference will increase somewhat when full data are in, because only 28 (8%) of the former group are still on MRP while 38 (27%) of the 1981 removals are incomplete as of the ending date for the questionnaire information (5/1/82).

As a whole, there appeared to be limited numbers of terminations of removed workers in the lead industries, although secondary smelters and battery plants had somewhat larger numbers of terminations of removed workers than primary smelters and remelter/recyclers in 1979-80 (see Table 3.12, and Appendix C). From 1979-1981, twenty-eight (6%) of the 501 removed workers were terminated while on removal. Of these 28, however, only one was from the primary smelting industry, while 10 came from secondary smelters, 4 from remelters/recyclers, and 13 occurred within the battery industry. Union seniority protections are generally stronger in primary smelting, and more of the plants in the secondary industry represented in our data may have been experiencing severe economic stress. (For these purposes "termination" included all workers who permanently left their place of employment because they were fired, quit, retired, went on permanent medical leave, or went on extended "layoff.")

Table 3.14 sheds some additional light on the dynamics of employment in the three industries and the possible use of terminations to avoid MRP costs. If firms within an industry had been generally trying to substitute fresh new workers for older workers who carried high lead levels in long term storage pools in their bodies from past high exposures, we would expect to find an increase in recent years of both terminations and new hires of lead-exposed workers. As can be seen inTable 3.14, both new hires and terminations appear to have declined somewhat in recent years in primary smelting and the battery plants with useable data. For the 4 remelters/recyclers with useable information the data indicate mainly economic stress--terminations are substantial, but

314

TABLE 3.14

SUMMARY OF WORKFORCE DYNAMICS IN THE MAJOR LEAD INDUSTRIES, BY INDUSTRY, 1977-1981*

INDUSTRY YEAR	# OF PLANTS	AVERAGE OVERALL WORK-FORCE	AVERAGE PRODUCTION WORKFORCE	AVERAGE # OF LEAD EXPOSED WORKERS	AVERAGE # OF LEAD EXPOSED NEW HIRES**	AVERAGE # OF LEAD EXPOSED TERMINATIONS**
PRIMARY SMELTERS (a)						
1977	5	473.6	396.8	436.2	85.8 (19.7%)	69.4 (15.9%)
1978	5	496.2	400.4	453.6	64.8 (14.3%)	49.4 (10.9%)
1979	5	508.0	413.6	465.0	78.2 (16.8%)	61.6 (13.2%)
1980	5	463.2	363.4	418.6	55.8 (13.3%)	35.8 (8.6%)
1981	5	537.6	433.8	492.4	63.0 (12.8%)	44.4 (9.0%)
REMELTERS RECYCLERS (b)						
1977	4	122.8	96.5	61.5	12.0 (19.5%)	11.8 (19.2%)
1978	4	120.8	96.3	61.8	11.3 (18.3%)	10.5 (17.0%)
1979	4	127.5	97.0	63.0	14.0 (22.2%)	16.8 (26.7%)
1980	4	105.5	78.8	46.8	0.5 (1.17%)	5.3 (11.3%)
1981	4	101.0	75.5	46.8	0.5 (1.1%)	6.5 (13.9%)

* Data from the Charles River Associates questionnaire. All "averages" are average figures per plant reporting data.

** These figures include summer and part time employees. The percentage of new hires (or terminations) is obtained by dividing the average number of lead exposed new hires (or terminations) by the average number of lead exposed workers.

(a) Includes 5 primary smelters: 1008912, 1040372, 1129272, 1199994, 1100272.

(b) Includes 4 remelters/recyclers: 1165212, 1100340, 1084298, 1098728.

TABLE 3.14 (continued)

SUMMARY OF WORKFORCE DYNAMICS IN THE MAJOR LEAD INDUSTRIES, BY INDUSTRY, 1977-1981*

INDUSTRY YEAR	# OF PLANTS	AVERAGE OVERALL WORK-FORCE	AVERAGE PRODUCTION WORKFORCE	AVERAGE # OF LEAD EXPOSED WORKERS	AVERAGE # OF LEAD EXPOSED NEW HIRES**	AVERAGE # OF LEAD EXPOSED TERMINATIONS**
Secondary Smelters						
1979 (c)	3	226.0	194.3	194.3	36.0 (18.5%)	38.7 (19.9%)
1980 (d)	4	153.5	145.3	145.0	22.0 (15.2%)	31.0 (21.4%)
1981 (e)	6	137.2	114.2	113.8	26.2 (23.0%)	27.8 (24.4%)
Secondary Smelters						
1977 (f)	3	133.3	113.3	113.3		
1978 (f)	3	139.3	123.7	123.7		
1979 (g)	6	136.7	117.0	117.3		
1980 (g)	6	119.0	100.7	101.0		
1981 (h)	8	115.1	95.1	95.3		

(c) Includes 3 secondary smelters: 1064018, 1036114, 1008052

(d) Includes 4 secondary smelters: 1064018, 1105012, 1008052, 1086114

(e) Includes 6 secondary smelters: 1064018, 1105012, 1008052, 1086114, 1036606, 1036126

(f) Includes 3 secondary smelters: 1064018, 1122514, 1086114

(g) Includes 6 secondary smelters: 1064018, 1132116, 1105012, 1008052, 1122514, 1086114

(h) Includes 8 secondary smelters: 1064018, 1036606, 1036126, 1132166, 1105012, 1008052, 1086114, 1122514

TABLE 3.14 (continued)

SUMMARY OF WORKFORCE DYNAMICS IN THE MAJOR LEAD INDUSTRIES, BY INDUSTRY, 1977-1981*

INDUSTRY YEAR	# OF PLANTS	AVERAGE OVERALL WORK-FORCE	AVERAGE PRODUCTION WORKFORCE	AVERAGE # OF LEAD EXPOSED WORKERS	AVERAGE # OF LEAD EXPOSED NEW HIRES**	AVERAGE # OF LEAD EXPOSED TERMINATIONS**
Industrial Battery Plant						
1977 (i)	3	151.7	131.3	83.3	28.7 (34.5%)	18.3 (22.0%)
1978 (i)	3	168.3	148.7	96.7	41.0 (42.4%)	36.3 (37.5%)
1979 (i)	3	159.7	138.0	87.7	16.7 (19.0%)	18.7 (21.3%)
1980 (i)	3	122.0	103.0	70.7	0.3 (0.4%)	8.0 (11.3%)
1981 (i)	3	109.3	91.7	63.7	0.7 (1.1%)	30.7 (48.2%)
Large SLI Battery Plants						
1977 (j)	4	367.3	323.3	233.3	65.0 (27.9%)	50.3 (21.6%)
1978 (k)	5	351.0	312.2	222.8	37.6 (16.9%)	36.2 (16.2%)
1979 (k)	5	328.2	290.2	204.2	19.0 (9.3%)	34.4 (16.8%)
1980 (k)	5	292.0	253.6	162.0	26.8 (16.5%)	27.0 (16.7%)
1981 (k)	5	316.6	278.2	192.2	27.0 (14.0%)	27.7 (14.2%)
Large SLI Battery Plants						
1977 (1)	9	321.6	287.4	205.5		
1978 (m)	10	332.2	295.6	214.8		
1979 (n)	11	289.5	253.5	174.3		
1980 (n)	11	276.5	234.0	156.6		
1981 (n)	11	279.9	233.7	161.5		

(i) Includes 3 industrial battery plants: 1021812, 1121084, 1144558

(j) Includes 4 large SLI battery plants: 1184234, 1043162, 1086514, 2189438,

(k) Includes 5 large SLI battery plants: 1086514, 1181646, 2189438, 1043162, 1184234

(l) Includes 9 large SLI battery plants: 1184234, 1043162, 1086514, 2189438, 2031384, 1106514, 1020952, 2061382, 1028128

(m) Includes 10 large SLI battery plants: 1086514, 1181646, 2189438, 1043162, 1184234, 2031384, 1106514, 1020952, 2061382, 1028128

(n) Includes 11 large SLI battery plants: 1086514, 1181646, 2189438, 1043162, 1184234, 2031364, 1106514, 1020952, 2061382, 1028128, 1101382

TABLE 3.14 (continued)

SUMMARY OF WORKFORCE DYNAMICS IN THE MAJOR LEAD INDUSTRIES, BY INDUSTRY, 1977-1981*

INDUSTRY YEAR	# OF PLANTS	AVERAGE OVERALL WORK-FORCE	AVERAGE PRODUCTION WORKFORCE	AVERAGE # OF LEAD EXPOSED WORKERS	AVERAGE # OF LEAD EXPOSED NEW HIRES**	AVERAGE # OF LEAD EXPOSED TERMINATIONS**
Medium SLI Battery Plants						
1977 (o)	4	111.3	97.5	77.3	13.5 (17.5%)	12.8 (16.6%)
1978 (o)	4	116.0	101.3	81.3	15.0 (18.5%)	10.5 (12.9%)
1979 (o)	4	112.3	99.5	78.3	9.8 (12.5%)	11.0 (14.0%)
1980 (o)	4	112.3	99.8	81.0	13.3 (16.4%)	13.0 (16.0%)
1981 (o)	4	116.3	102.0	73.8	18.0 (24.4%)	17.3 (23.4%)
Medium SLI Battery Plant						
1977 (p)	7	128.5	112.1	90.9		
1978 (p)	7	130.4	112.7	93.0		
1979 (q)	8	110.4	94.4	79.0		
1980 (q)	8	109.2	93.2	78.4		
1981 (q)	8	112.0	97.1	78.9		
Small SLI Battery Plant						
1977 (r)	3	25.7	18.3	20.0	2.3 (11.5%)	2.3 (11.5%)
1978 (r)	3	27.3	20.0	21.7	3.7 (17.0%)	2.3 (10.6%)
1979 (r)	3	28.0	20.0	21.7	4.3 (19.8%)	3.0 (13.8%)
1980 (r)	3	29.7	21.3	23.0	4.0 (17.4%)	2.3 (10.0%)
1981 (r)	3	31.7	22.7	24.3	4.7 (19.3%)	2.3 (9.5%)

(o) Includes 4 medium SLI battery plants: 1168132, 1082366, 1119614, 1060758

(p) Includes 7 medium SLI battery plants: 1168132, 1082366, 1119614, 1060758, 1021526, 1021468, 2121084

(q) Includes 8 medium SLI battery plants: 1168132, 1082366, 1119614, 1060758, 1021526, 1021468, 2121084

(r) Includes 3 small SLI battery plants: 1174266, 1012010, 1061840 the size of the lead-exposed workforce has declined and there are almost no lead-exposed new hires. Only very limited data were available for the secondary smelting industry; what there is suggests the possibility that new hire rates and terminations are relatively high but the absence of comparable data for 1977 and 1978 prevents us from drawing any conclusion other than that the information is not inconsistent with some use of termination to reduce prospective MRP costs*. However, low lead prices and the reduced market for lead automobile batteries during the 1979-81 period may have caused terminations of many workers regardless of the presence of the MRP program. Our limited conversations with labor and management indicate that this is not likely to be a widespread practice.

The median blood lead at removal was 79 and the median level at return was 49. The blood lead at removal remained relatively high throughout 1979-1981, consistent with the deferred implementation of the 60-40 removal-return triggers. Also, the blood lead levels for 1979-1981 were relatively high because there were many individuals removed with high Pb-B during the 1979-1980 start-up period. Detailed data for individual industries are shown in Appendix C. There appeared to be a tendency for median blood lead levels for removal and return to decrease between 1979-80 and 1981 for all of the individual lead industries (as would be expected with the lowering of the triggers from the initial 80-60 levels) although it is not certain that this trend is statistically significant.

We can now proceed to roughly estimate the current costs associated with the medical surveillance and removal of the MRP programs. The costs of blood lead and air lead monitoring, and medical exams were summarized by Charles River Associates on the basis of their survey results along with other ongoing administrative expenses (Table 3.15). It can be seen that these monitoring costs add up to about $400 per lead-exposed worker. The removals themselves, from Table 3.11 have amounted to something like 2% of total worktime for battery manufacturers and primary smelters. Since at that rate of transfer there are low exposure jobs available, typical costs are (wage differentials = about $6,000 based on the experience of our case study battery manufacturer) x .02 = $120 per lead-exposed worker per year. We do not have representative data for 1982, after the 60/40 triggers were implemented. Based on interviews and the original model projections[6] we estimate that the number has risen to about 5-10% of the total available work time. Removal costs then would be about $300-$600 per lead exposed worker per year, again assuming that a substantial number of paid layoffs are not required, as has been the experience so far.

---

*In at least one secondary smelting plant there appears to have been litigation over this issue. The case was settled out of court.

The situation in the secondary smelting industry is more confusing. The firms we have interviewed have had blood lead experience similar to that of the battery plants; however, the data we compiled from the survey questionnaires indicates that perhaps as much as 7% of the workforce may have been on MRP transfer as a yearly average in 1981, and presumably even more in 1982.

At high levels of MRP transfer the costs can increase significantly, and many plants in all three industries could be faced with this problem for at least some transition period if the final 50/40 MRP triggers go into effect. One battery manufacturer estimates that the number of jobs open for MRP transfers is 10-15% of the jobs in a plant;

TABLE 3.15

Reproduced from best available copy.

TOTAL MONITORING AND ADMINISTRATIVE COSTS OF COMPLIANCE WITH THE EXISTING OSHA LEAD STANDARD, BY INDUSTRY

Industry	Plants (#)	Total Employees (#)	Lead-Exposed Employees (#)	Costs Per Lead-Exposed Employee: Monitoring* ($)	Lunchroom/ Changeroom ($)	Respirators ($)	Uniforms and Laundering ($)	Training ($)	Total Per Lead-Exposed Individual ($)	Industry Costs (millions)
Primary	6	3,048	2,790	410	359	306	743	113	1,931	5.39
Secondary	31	3,578	3,010	482	359	306	743	113	2,003	6.03
Batteries	116	17,930	12,035	356	359	306	743	113	1,877	22.59
>3000	47	12,100	8,256	359	359	306	743	113	1,880	15.52
1200-3000	18	1,800	1,208	359	359	306	743	113	1,880	2.27
<1200	51	990	665	337	359	306	743	113	1,858	1.24
Industrial	20	2,048	1,906	350	359	306	743	113	1,871	3.57
Recycling	17	3,171	1,208	322	359	306	743	113	1,848	2.21
Total	190	27,727	19,043						1,901	36.24

SOURCE: Charles River Associates, based on cost information supplied by companies in a questionnaire.

*Includes recordkeeping. Figures in this column are taken from Tables 4.4, 4.6, 4.9, and 4.11.

the range represents variation from plant to plant, and the percentage would increase with the further implementation of engineering controls. Once the number of MRP transfers exceeds the number of open positions, the cost becomes proportional to total wage, rather than a wage differential; thus the cost per 1% transfers becomes aproximately $25,000 x .01 = $250 per lead-exposed worker per year, and going from 10% to 20% MRP transfers might cost an additional $2,500 per lead exposed worker in "unproductive" wage payments.

So far we have only considered lost wages as an MRP cost to the employer. That is a reasonable assumption when the industry reaches long term equilibrium, because employers will be able to hire and train the appropriate mix of workers. In the short run, as groups of workers suddenly go on MRP when new triggers are instituted, and when it is not easy to estimate the effectiveness of new controls or the expected duration of an MRP transfer, there can be significant losses of productivity as teams of workers are broken up, or there are shortages of people trained in certain jobs. One battery manufacturer has estimated these additional losses in productivity to be amounts that are approximately equal to the lost wage differentials at 0-5% MRP transfers, that are twice as large as the lost wage differentials at 5-10% MRP and that are four times lost wage differentals if there are over 10% MRP transfers. These effects might apply for as much as a year or two during the initial phase-in period for the new triggers.

In conclusion, we can say:

1) The numbers of people put on MRP so far are small enough (at most a few percent, that they cannot have significantly distorted the blood lead distributions discussed in Sections 3.3 and 3.4 above and we need not modify our previous conclusions about effective air lead

exposures.

2) There have not been mass firings with the implementation of the MRP program in the stable industries, primary smelting and large battery manufacturers; the situtation in secondary smelting is unclear because of the economic difficulties and ongoing consolidation of the industry (see further discussion in Section 3.6 below)

3) The length of time on MRP can be quite long for a small minority of workers. This is in accord with model predictions for long-tenured workers if transfered to work areas with as much as 30 ug/m^3 air lead levels[10]. The original model calculations done prior to the standard assumed lower effective exposure levels than this for transferred workers.

4) The current costs of MRP removals appear relatively modest compared to other ongoing costs of the lead standard. However, the prospect of much larger costs and disruption of production from MRP transfers and layoffs of experienced workers appears from our interviews to have been a major motivator for the full range of other measures taken to reduce worker exposures to lead.

3.6 Technology and Economics of Controlling Occupational Lead Exposure

We begin this section by looking at the control measures which have been introduced and which are presumably responsible for the declines in air lead and blood lead levels discussed above. Based on the analysis in the CRA report we then consider the distribution of air lead levels within different operations in the plants of all three industries, with the goal of assessing the feasibility of further reductions in lead exposure. We continue to follow the CRA report in estimating the costs and benefits of investment in both conventional add-on controls and in new process technology, and then discuss the prospects for such investments in light of the current economic condition of the lead industries.

3.6.1 Recent Investments in Control

We do not have a great deal of information on the costs and effectiveness of measures used across the three industries to bring exposures down to their present point. However from our case study work we can present some general impressions and information for a few firms.

In Table 3.15 (p. 3-46) of the previous section, we have already reproduced the results of a general survey of current yearly industry expenditures for controls in the categories C-1 (respirators), C-2 (showers,etc.), and D-1 (medical surveillance) of our taxonomy of control measures (Table 1.1, p. 1-10 above). It should be noted that these cost figures include overhead expenses. We have compared these results with data provided by a non-representative sample of 1 primary smelter, two secondary smelters, and 7 battery manufacturers, and found agreement to within about 50%.

We have looked at the capital expenditures of this same sample for controls in catagories A and B, (it is not possible, unfortunately, to disaggregate them further). The primary smelter has spent approximently $1,500 per lead exposed worker per year over the four year period 1977-81 in this category. Most of this expenditure was for improved ventilation in the sinter plant. The two secondary smelters have made capital investments of approximately $1,700 per worker per year in catagories A and B for the two years 1981-2. The seven battery plants spent approximately $800 per worker per year in the same period. It is not possible to estimate operation and maintenance costs associated with this equipment from the data available.

These are not inconsiderable expenditures. However, as we shall see later, they do not appear to approach the overall magnitude of cost projected by CRA as needed to implement all the engineering controls that might be considered feasible within a few additional years as provided by the OSHA standard.

3.6.2 Current Distributions of Exposure by Plant Area

CRA's engineering estimates of costs for control of lead to various levels in primary and secondary smelters were based on case studies of two plants in each industry. Tables 3.16 through 3.19 summarize the starting points for the case study plants. In each case, we have arranged the worker groups in approximate order of the flow of material through the plants--starting with batteries or concentrate and finishing with refined metal. It can be seen that most plants have high concentration areas/processes where control to the 50 ug/m^3 air standard will require many-fold reductions in exposure. This is particularly evident in

Table 3.16

Exposures in Primary Lead Smelter No. 1 by Plant Area

Plant Area	No. Workers	Ave. Air Levels (ug/m^3 --1981)	Total Exposure* (person-ug/m^3)	% Total Exposure
Materials handling	34	348	11,833	6.2
Sinter Plant	44	1,816	79,884	41.8
Furnace Area	68	767	52,187	27.3
Dross Plant	28	748	20,932	11.0
Refinery	90	140	12,587	6.6
Baghouse	15	204	3,065	1.6
Yard and Maint.	210	about 50**	about 10,500	5.5
TOTAL	489	about 390	about 191,000	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.2 (pp. C-79 to C-84) of the Charles River Report.

**Estimate from page F-55 of Charles River Report

Table 3.17

Exposures in Primary Smelter No. 2 by Plant Area.

Plant Area	No. Workers	Ave. Air Levels (ug/m^3) (1981)	Total Exposure* (person-ug/m^3)	% Total Exposure
Materials handling	35	170	5,950	3.6
Sinter Plant	36	1,775	63,887	39.1
Furnace Area	41	1,550	63,570	38.9
Dross Plant and Refinery	62	298	18,501	11.3
Baghouse and Acid Plant	26	448	11,635	7.1
Other (headquarters staff, etc.)	about 200	Exposures not given		
TOTAL (excluding (headquarters)	200	818	163,543	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.2 (pp. D-63 to D-68) of the Charles River Report.

Table 3.18
Exposures in Secondary Smelter No. 1

Plant Area	No. Workers	Ave. Air Levels (ug/m^3) (1979-80)	Total Exposure* (person-ug/m^3)	% Total Exposure
Yard labor	5	89	445	3.0
Separator Area (incl. battery breaking)	10	378	3,780	25.1
Mixing Room (Charge Preparation)	4	310	1,240	8.2
Furnace Charging	8	338	2,704	18.0
Furnace Tapping	12	316	3,792	25.2
Refining and Kettle Operations	9	266	2,394	15.9
Casting, Skimming Stacking	5	100	500	3.3
Shipping and Receiving	3	63	189	1.3
TOTAL	56	269	15,044	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.2 (pp. A-59 to A-70) of the Charles River Report.

Table 3.19
Exposures in Secondary Smelter No. 2

Plant Area	No. Workers	Ave. Air Levels (ug/m^3) (1981-2)	Total Exposure* (person-ug/m^3)	% Total Exposure
Front-end Loader operator	1	272	272	2.2
Yard Jockey	2	138	276	2.2
Battery Breaking	6	180	1,080	8.7
M.A. Operator (materials separation e.g. battery cases from other battery components)	4	316	1,264	10.2
Hoist Operator	4	522	2,088	16.9
Payloader Operator	4	422	1,688	13.6
Furnace Operator	4	656	2,624	21.2
Refining (Potman)	4	165	660	5.3
Agglomerator operator	3	811	2,433	19.6
TOTAL	32	387	12,385	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.1 (pp. B-53 to B-64) of the Charles River Report.

primary smelting,where ambient exposures for the sintering and blast furnace departments are in the range of 700-1800 ug/m^3.

The CRA report and its suppement by Kaplan[22] unfortunately did not present information of this kind for battery plants. However it is our impression that paste mixing, grid casting, and plate breaking are major sources of emission/exposure in that industry.

3.6.3 The Potential and Cost of Future Engineering Controls, Including New Technology

The current OSHA standard does not require that the mandated air level of 50 ug/m^3 be met under all conditions by engineering controls in all areas in lead-producing or -using plants. Rather, it requires that where air levels are above this value, all "feasible" engineering control measures be taken to reduce them*. Thus the plant-by-plant determination of what is "feasible" is a central factor in determining the ultimate costs and benefits of the OSHA lead standard. In this subsection we will attempt to give some overview of the issues involved in deciding what measures are feasible for each of the industries, what those might cost, and what they might accomplish in terms of reduced worker exposure. One of the more surprising overall conclusions of the Charles River analysis was that there appeared to be very little difference between the engineering control measures (and associated costs and exposure reductions) that would be required in practice by OSHA permissible exposure limits of 50 vs 150 ug/m^3. Total industry-wide annualized before-tax costs* (in millions of 1982 dollars) for the engineering and work practice controls examined by CRA were:

---

*The exact wording places the burden of proof to show that specific controls are not feasible on the employer:

> Where any employee is exposed to lead above the permissible exposure limit for more than 30 days per year, the employer shall implement engineering and work practice controls...except to the extent that the employer can demonstrate that such controls are not feasible. Wherever the engineering and work practice controls which can be instituted are not sufficient to reduce employee exposure to or below the permissible exposure limit, the employer shall nonetheless use them to reduce exposures to the lowest feasible level....

	150 ug/m^3	50 ug/m^3
Primary Smelting	15.5****	16.0**
Secondary Smelting	24.5**	26.4**
Battery Industry	97.4**	Not done***

This was because:

- o in many areas within the three industries, even the most extensive controls considered by the evaluating engineers would not keep exposures below 150 ug/m^3 at all times, and
- o in some other areas, where control to 150 ug/m^3 was achievable, little or no additional effort and cost would be required to achieve compliance with a 50 ug/m^3 limit.

*Ammortizing capital costs over the estimated life of the equipment and assuming a 6% discount rate.

**Total of estimates of all conventional engineering, isolation and work practice controls considered feasible by CRA--data from Table 6.2, p. 6-6, Table 7.3, p. 7-9, the discussion of primary smelters on pp. 5-2 to 5-4, and thediscussion of secondary smelters on pp. 6-1 to 6-3 of the Charles River Report. Data for the battery industry were computed by subtracting the estimate of administrative costs from total before-tax annualized costs reported by CRA in Table 7.3. Data for the primary smelting industry were projected by us from a capacity-based formula provided by CRA and the capacities of individual smelters.

***Diffrences between controls under 150 and 50 standards are said by Charles River to be small. However their analysis excluded the costs of possible changeover to promising new expanded metal technology for battery manufacture.

****Projected from the figure derived for the 50 ug/m^3 standard and the ratio of total annualized costs for the two plants for the 150 and 50 standards.

The latter condition often seemed to be the case where it was considered feasible to provide an isolated control booth (or a cab on mobile equipment) with filtered air for specific workers. The provision of these work areas was brought up as an issue in different ways in our interviews with both labor and management.

Management representatives we spoke to offered the booths as an example where labor was using health and safety issues to advance other worker interests in better working conditions--in particular, the request by labor for air conditioning in these facilities. In response, a labor representative said that because of the open air design of primary smelters and some secondary smelters it was unrealistic to expect workers to stay in the booths for long periods without air conditioning, and therefore the air conditioning made a legitimate and necessary contribution to the overall exposure-reducing program.

The labor representative also spontaneously brought up the booths as the main example of the practical difference between maintaining the permissible exposure limit at 50 ug/m^3 vs. effectively raising it (as currently proposed by OSHA[12]) to 150 ug/m^3. With a good maintenance program (changing filters regularly, etc.) he believed that the booths could generally keep lead levels to an average of 20-30 ug/m^3. In the absense of good maintenance, conditions would deteriorate and lead levels would be many times this. He was concerned that the proposed increase in the engineering control permissible exposure limit would have the effect of allowing this kind of neglect and the consequent higher exposures when it was clearly feasible to avoid it.

Based on our classification system for control measures, (Table 1.1 above) we have sorted the control measures considered feasible by the CRA engineers into three broad groups:

- (A-2) Source-reducing engineering and ventilation controls--such as enclosing/ventilating dust-emitting processes; automating certain operations or installing other process improvements to reduce labor or improve containment

- (B-1) Isolation--surrounding the worker(s) with control booths or cabs with filtered air

- (A-3 and B-2) Work practices--such as improved training to deal with upset situations, better housekeeping (allowing less accumulation of dust on floors by more frequent cleaning, etc.)

Tables 3.20 and 3.21 show the costs and estimated contributions to overall exposure reduction for the different kinds of control measures for the four plants studied in detail by CRA. This breakdown reveals some curious differences, both within and between the two industries. In secondary smelter No. 1, isolation measures appeared to be very important--providing over half of the overall exposure reduction while amounting to less than 20% over the overall expenses. Work practice improvements also were projected as making an appreciable contribution to exposure reduction in that plant. In the second secondary smelter, work practice improvements were judged capable of providing only relatively small benefits; the major exposure reductions were provided by some relatively creative process changes (including some Bergsoe technology) supplemented by an appreciable (20%) contribution from isolation type control measures.

By contrast, there was very little in the way of isolation controls and no work practice improvements among the measures considered feasible by the CRA engineers for the two primary smelters studied. Isolation controls contributed only 0.5-3% of the exposure reduction and 0.3-0.5% of the annualized costs of control in the two plants. There is no discussion

Table 3.20
Secondary Lead Smelters--Comparison of Costs and Air Lead Exposure Reduction Attributable to Different Kinds of Controls

Smelter and Type of Control Measure	Exposure Reduction* (person-ug/m^3	% Total Exposure Reduct.	Annualized Costs (thousands of $, 1980)	% Total Annualized Costs
Secondary Smelter No. 1				
Source-reducing engineering controls and ventilation	3,045	26	535	69
Isolation (e.g. control booths with filtered air supply, lunchroom isolation)	6,775	57	147	19
Work practices (e.g. housekeeping)	2,044	17	96	12
Total	11,864	100	778	100
Secondary Smelter No. 2			Thousands of 1982 dollars	
Source-reducing engineering controls and ventilation	7,766	80	518(gross) 428(net)**	77
Isolation (e.g. control booths with filtered air supply, lunchroom isolation)	1,777	18	70	13
Work practices (e.g. housekeeping)	186	2	58	10
Total	9,729	100	557(net)**	100

*Compiled from detailed data on pp. A-84 to A-86 and pp. B-79 to B-80 of the Charles River Report.

**Net costs are after subtraction of $90,000 in annual costs saved due to a reduction in the number of workers required because of process changes in battery breaking, charge preparation, and agglomeration of dust in exhaust gases.

Table 3.21
Primary Smelters--Comparison of Costs and Air Lead Exposure Reduction Attributable to Different Kinds of Controls

Smelter and Type of Control Measure	Exposure Reduction* (person-ug/m^3	% Total Exposure Reduct.	Annualized Costs (thousands of $, 1980)	% Total Annualized Costs
Primary Smelter No. 1				
Source-reducing engineering controls and ventilation	93,989	97	4,426	99.5
Isolation (e.g. control booths with filtered air supply, lunchroom isolation)	3,034	3.1	21	0.47
Work practices (e.g. housekeeping)	-----	--	---	--
Total	97,023	100	4,447	100
Primary Smelter No. 2				
Source-reducing engineering controls and ventilation	76,080	99.5	4,346	99.7
Isolation (e.g. control booths with filtered air supply, lunchroom isolation)	400	0.5	13.5	.3
Work practices (e.g. housekeeping)	-----	--	--	--
Total	76,480	100	4,360	100

*Compiled from detailed data on pp. C-90 to C92 and pp. D-73 to D-75 of the Charles River Report.

in the CRA report that allows us to determine whether this represents a well-studied judgment by CRA that these types of controls in fact have very limited potential for additional use or improvement in primary smelters, or whether this represents simply an orientation toward more source-reducing and ventilation type controls on the part of the individual engineers that did the primary smelting studies. On the basis of our site visit to one primary smelter, and statements of the labor interviewee, we suspect that the CRA analysis understates the potential for exposure reduction from improved isolation and work practices in primary smelting.

This suspicion emerges even more strongly when we summarize the overall exposure reductions expected by CRA for their four case-study plants:

Industry	Plant No.	No. Workers	Average 1981 Exposures	Average Exposure Expected After Conventional Controls*	% Reduction
Secondary	1	56	269	57	79
Smelting	2	32	387	83	79
Primary	1	489	390	192	51
Smelting	2	200	818	435	47

If OSHA were to adopt the detailed measures specified in the CRA report as their working definition of "feasible" measures, much larger percentage reductions in exposure would be accomplished in secondary smelting than in primary smelting; and primary smelters would be left with average levels many times higher than the 50 ug/m^3 guideline. The secondary industry would achieve average exposures much closer to the guideline although exposures would still considerably exceed 50 ug/m^3 in some plant areas.

---

*All measures summarized in Tables 3.20 and 3.21

One of the most interesting possibilities examined by the CRA report for achieving additional control of exposures in the primary smelting industry was the use of fundamentally new "direct smelting" processes in place of the sinter machine and blast furnace of the current process. (In the current process the sinter machine first converts the lead sulfide ore to lead oxide, and the blast furance reduces the lead oxide to lead metal with coke. In the "direct smelting" processes lead sulfide is converted to lead metal in one step, and the fuel value of the conversion of the sulfide to sulfur dioxide is used to help drive the reaction.) We examine this subject in some detail in comparison with the details of the conventional engineering control program in Appendix B. In general it appears that for the one case-study plant (Primary Smelter No. 1) the new technology would bring considerable additional reductions in exposure (about 40% lower than the post-control level shown above for conventional controls) at an additional annualized before-tax cost of about $2.5 million (this is about a 56% increase in total annualized costs for that plant). Some of the costs of the new system are offset by savings in labor requirements and coke. Because of the increase in capital expenditures for the new system* (bringing investment tax credits and depreciation benefits) and the savings in operating costs**, CRA estimated that on an after-tax basis there would actually be a small annual net financial benefit ($0.8 million) to a firm implementing the new technology instead of their postulated conventional control program. (Source: Table

---

*From a total of $17 million for controls without the new system to total capital costs of $134 million with the new system.
**Amounting to about $9 million per year.

4.2, pp F-58 to F-59 of the CRA report.) This is, of course, before adding in any savings of MRP costs.

All of these calculations are for converting an existing smelter, with its refining operations intact to the new technology. In the case of a brand new smelter, CRA estimates that the new technology would have a clear cost advantage--amounting to something like 2 cents per pound of lead produced. (This is because in the case of building a new smelter, the capital costs of building with the new technology are much closer to the capital costs of building with the old technology than in the case of a comparison of a high capital/low operating cost new-technology-retrofit with a low-capital/high operating cost conventional-technology retrofit.) Therefore it seems likely that one of the direct smelting technologies examined by CRA would be used in any new smelter constructed in the next few years--and CRA expects that such a new smelter will be needed to handle the anticipated output of new mine production expected to come on stream in the next several years.

Unfortunately, we do not have the facts available for a full quantitative analysis of likely costs and exposure-reduction benefits for available new technology in either the secondary smelting or battery industries.

There are also some promising technological developments in the secondary smelting and battery industries, though only one possibility quite as dramatic on a scale of process change as in primary smelting.

A Danish firm (Paul Bergsoe and Son) has recently constructed a new smelter in St. Helens, Oregon based on a shaft furnace (in contrast with the traditional two-stage reverberatory/blast furnace system), improvements in the battery breaking process, and in the process for handling dust in the exhaust gases (the dust is agglomerated, which reduces emissions during recycling). The new smelter reportedly does not fully meet a 50 ug/m^3 standard by engineering controls alone, but it is an improvement over older systems. To facilitate compliance with off-site EPA ambient air quality standards, the process is in a completely enclosed building.

Using more conventional smelting technology, but its own new proprietary battery breaking system, Gould has recently built a new secondary smelter in Los Angeles on the site of an old plant it bought from NL industries in 1979[13]. The new plant also has an improved covered system for conveying molten lead from the smelting furnace and improved ventilated systems for conveying dust.

The Charles River Report also speaks favorably of the prospects for using oxygen enrichment in the blast furnaces of secondary smelting plants--in one U.S. smelter, enriching the air to 30% oxygen reportedly resulted in a 63% decrease in lead fume production.

Finally, as of late 1981, the Italian firm of Elettrochimica MarcoGinatta claimed to have successfully operated for over a year a 2,200 ton/year demonstration plant that recovered lead from batteries by an electrochemical process[14]. Lead in the battery electrodes is reportedly dissolved while still in the battery case and then recovered by depositing it on a cathode, (much as copper is now refined). The cost was reportedly competitive. Unfortunately, we have found no subsequent mention of the further progress of this radical development in easily available publications in this country. The Charles River Report is generally pessimistic about the near term prospects for hydrometallurgical approaches such as this for both primary and secondary lead smelting.

Unlike the primary and secondary smelting industry, innovation in the battery industry is at least as much in the form of new products as new processes. Where product change is rapid, it is important to maintain some flexibility in production processes, and this tends to limit the amount of capital-intensive integrative continuous design that it is prudent for manufacturers to utilize for production. Nonetheless, a pronounced trend toward consolidation in the industry in conjunction with transitions to smaller batteries, containing less lead, and relying on lead-calcium rather than lead-antimony alloys has provided the opportunity for substantial design changes and improved automation as new plants are built to make the new batteries.

For the battery industry, the Charles River report mentioned one important process change as likely to make an appreciable contribution to the reduction of exposures. This is the "expanded metal" process for forming battery grids. In the conventional process, the grids are cast from molten lead. In the "expanded metal" process, a coil of metallic lead sheet is cut at intervals, expanded, pressed to an appropriate thickness, and then fed into a new kind of pasting machine (the "paste" is lead oxide and water) which covers both sides with a special paper before applying the paste. The paper helps hold the paste through subsequent operations and minimizes dust after the paste has dried. Reportedly, air lead levels using this kind of process

> were generally below 200 ug/m^3 with virtually no exhaust ventilation and generally below 50 ug/m^3 with modest ventilation (p. 24 of Appendix H in the CRA report).

This new process technology appears to be being introduced hand in hand with new product technology in the battery industry. The expanded metal process is best adapted for use with the newer lead-calcium alloy batteries that appear to be replacing traditional lead-antimony alloy batteries. Machines using it also appear to have very high capacities, which introduces a substantial economy of scale for larger operations (or, on the other hand, substantial diseconomies for specialty manufacturers who wish to make only a few batteries for a narrow market segment. It is possible, however that this situation has been produced by the fact that many early adopters of the technology have been large concerns. The labor representative suggested that if smaller battery manufacturers were required to adopt the technology, a demand would be created for lower-capacity, more flexible, and cheaper machines of this type. We are not in a position to evaluate the feasibility of such modifications to the design of machines using the expanded metal technology). The net before-tax cost of the technology appears to be on the order of $.20 per battery for larger producers--approximately a 20% addition to the average before-tax real cost of compliance for the SLI battery industry as a whole.

3.6.4 Discussion of Overall Costs in the Light of the Economic Condition of the Industries

Table 3.22 summarizes the overall costs of lead control as determined in the sections above, excluding for the moment any costs or benefit from the implementation of new technology. For all three industries, annual costs from the future implementation of new engineering controls are by far the largest item. Administrative and monitoring costs also make an appreciable contribution representing about a quarter to a third of the total; the estimated costs of MRP removals appear to be at most 5-10% of the costs of compliance. Because of this, it would not affect overall estimated costs very much if we were to include some credit for reduction of MRP costs due to the exposure reduction expected from the installation

Table 3.22

Summary of Overall Costs of Lead Control

Annualized Real Costs Before Taxes (Millions of 1982 Dollars)

[Capital costs were annualized over the life of the equipment (in general 10 years) at a 6 percent real discount rate]

Type of Control Measure	Primary Smelters	Secondary Smelters	Battery Plants
Currently-Ongoing Administrative and Monitoring Costs:*	5.39	6.03	22.6
Medical Removal Protection (costs after implementation of 60/40 triggers as projected by us)	0.9-1.8	0.9-1.8	3.6-7.2
Future Conventional Industrial Hygiene Controls**	16.0	26.4	97.4 (does not include costs of conversion to expanded metal process)
TOTAL COSTS	about 23	about 34	about 125

*Data from Table 4.13, p. 4-20 of the Charles River Report

**Total of estimates of all conventional engineering, isolation and work practice controls considered feasible by CRA--data from Table 6.2, p. 6-6, Table 7.3, p. 7-9, and the discussion of primary smelters on pp. 5-2 to 5-4 of the Charles River Report. Data for the battery industry were computed by subtracting the estimate of administrative costs from total before-tax annualized costs reported by CRA in Table 7.3. Data for the primary smelting industry were projected by us from a capacity-based formula provided by CRA and the capacities of individual smelters. Results do not take into account likely savings of MRP costs due to reduced exposures.

of engineering controls. Aggregate costs in the battery industry appear to be more than double those in primary and secondary lead smelting combined--presumably because there are many more workplaces to control and workers to protect.

Tables 3.23 and 3.24 summarize these same results in two other perspectives--as additions to the costs of labor, and the costs of lead production or use. Table 3.23 indicates that on a per-worker basis, annualized costs of control in the three industries are relatively close to one another, with the program in primary smelting coming in somewhat lower than control programs in the secondary smelting and battery industries. As we said earlier, however, we suspect that greater use could be made in primary smelting of isolation and work practice controls than was postulated by CRA. Additional controls of these types, and/or a program to substitute direct smelting processes for the sinter machines and blast furnaces throughout the industry, could increase the costs per worker beyond those seen for secondary smelting and battery manufacture. Viewed in the perspective of labor costs, the overall increments of more than $10,000 per lead-exposed worker are appreciable.

Table 3.24 shows the costs as increments to the cost of producing or using lead. Viewed in the perspective of today's depressed lead price of about 20 cents per pound, additional expenses of somewhat under 2 cents/lb for the primary and secondary smelting industries represent a perceptible, but not a dramatic increase. However, this facile comparison tends to conceal a crucial distinction between the positions of primary and secondary smelting. Lead is in fact not the only main revenue-generating

Table 3.23

Summary of Overall Costs of Lead Control

Annualized Costs Per Lead-Exposed Worker*** (1982 Dollars)

[Capital costs were annualized over the life of the equipment (in general 10 years) at a 6 percent real discount rate]

Type of Control Measure	Primary Smelters	Secondary Smelters	Battery Plants
Currently-Ongoing Administrative and Monitoring Costs:*	1,931	2,003	1,877
Medical Removal Protection (costs after implementation of 60/40 triggers as projected by us)	300-600	300-600	300-600
Future Conventional Industrial Hygiene Controls**	5,250	8,770	8,090 (does not include costs of conversion to expended metal process)
TOTAL COSTS	about 7,600	about 11,200	about 10,400

*Data from Table 4.13, p. 4-20 of the Charles River Report

**Total of estimates of all conventional engineering, isolation and work practice controls considered feasible by CRA--data from Table 6.2, p. 6-6, Table 7.3, p. 7-9, and the discussion of primary smelters on pp. 5-2 to 5-4 of the Charles River Report. Data for the battery industry were computed by subtracting the estimate of administrative costs from total before-tax annualized costs reported by CRA in Table 7.3. Data for the primary smelting industry were projected by us from a capacity-based formula provided by CRA and the capacities of individual smelters. Results do not take into account likely savings of MRP costs due to reduced exposures.

***Based on CRA's estimates of 3,048 lead-exposed workers in six primary smelters; 3,010 lead-exposed workers in 36 secondary smelters; and a total of 12,035 lead-exposed workers in 136 battery plants (including 20 industrial battery plants. Data presented here exclude the 1,208 lead-exposed workers in 12 recycling/remelting plants.

Table 3.24

Summary of Overall Costs of Lead Control

Annualized Costs Per Pound of Capacity to Produce or Consume Lead***
(Cents/Lb)

[Capital costs were annualized over the life of the equipment (in general 10 years) at a 6 percent real discount rate]

Type of Control Measure	Primary Smelters	Secondery Smelters	Battery Plants
Currently-Ongoing Administrative and Monitoring Costs*	.415	.297	1.06
Medical Removal Protection (costs after implementation of 60/40 triggers as projected by us)	.07-.14	.044-.089	.17-.34
Future Conventional Industrial Hygiene Controls**	1.23	1.30	4.57****
TOTAL COSTS	about 1.75	about 1.66	about 5.9

*Data from Table 4.13, p.4-20 of the Charles River Report--See pp. for breakdown of components.

**Total of estimates of all conventional engineering, isolation and work practice controls considered feasible by CRA--data from Table 6.2, p. 6-6, Table 7.3, p. 7-9, and the discussion of primary smelters on pp. 5-2 to 5-4 of the Charles River Report. Data for the battery industry were computed by subtracting the estimate of administrative costs from total before-tax annualized costs reported by CRA in Table 7.3. Data for the primary smelting industry were projected by us from a capacity-based formula provided by CRA and the capacities of individual smelters. Results do not take into account likely savings of MRP costs due to reduced exposures.

***Based on CRA's estimates of 650 thousand tons/year production capacity in the primary lead industry; 1,015 thousand tons/year production capacity in the secondary lead industry, and lead-exposed workers in 36 secondary smelters; and a total of approximately 2.13 billion pounds per year of lead-using capacity in 136 plants in the battery industry (projected from the 75% reported capacity utilization in 1981 in the SLI battery industry and the 726,000 metric tons of lead consumption in 1981.)

****Does not include costs and benefits of conversion to the expanded metal process.

product of the primary lead industry. The smelting and refining of "lead concentrate" also results in appreciable production of silver, bismuth, antimony, zinc, copper, gold, and sulfur "byproducts". As is discussed in Appendix B (p. B-19 to B-23), in 1980 when prices for lead (and probably most byproducts) were much higher than they are today, lead sales represented only about one third of the total revenue generated by the primary lead industry. For the secondary industry, lead is in fact the primary revenue-generating product. Thus incremental costs that are equal per pound of lead produced in the primary and secondary smelting industries are likely to have a much more severe impact on secondary producers.

For the battery industry, the incremental costs of about six cents per pound of lead-using capacity represent a fairly serious addition to the costs of using lead. It is CRA's assessment that at least in the next decade, technological developments in the battery industry are unlikely to proceed to the point where battery systems that do not use lead are likely to be important competitors for the major battery market--Starting, Lighting and Ignition batteries primarily used in automobiles. However, the costs of controlling lead in the battery industry may somewhat increase the incentives for the long term development of alternative non-lead battery systems.

All of these prospective costs, and the promise and risks of new production technology, must be viewed in the perspective of the recent economic history of the industries. Like many other basic metals industries, the lead industry has gone through a roller coaster ride over the last several years and is now in a severe depression. Table 2.7 (p. 2-27 above) gives historic prices of lead in constant dollars as of the middle of 1982. In late 1982 and early 1983 the situation deteriorated even further, with lead prices staying on the order of 20-23 cents per pound. There was a heady period in the late 1970's during which prices and worldwide consumption were strong, inflation and high energy costs seemed to make basic materials prices a very attractive speculation for the future, and there was substantial investment in new production capacity--both in the U.S. and worldwide. In addition to the demand from booming new car sales, the Soviet Union was evidently buying substantial amounts of lead from the West on the open market.[14] More recently, lower new car sales and relatively mild winters have reduced demand for batteries, and there is also reduced demand for lead in leaded gasoline. Nonetheless some substantial fraction of primary production capacity has been kept running not because of its value in producing lead, but because of the major profits to be made from selling by-product silver and other metals.[15]

One factor that has not been an important problem for the domestic industry has been foreign competition. Little lead is now imported, and there is a small tarriff barrier (3.5% ad valorem, but with a floor of 1.0625 cents per pound--the result of trade negotiations between the United States andd Mexico in 1980) that is expected to be renewed before it expires on June 30, 1983.[16]

The overall market situation has caused major economic distress in the secondary lead industry and at least some consolidation in the primary industry. Early in 1982 the 118,000 ton/year Bunker Hill primary smelter/refinery in Idaho closed--representing about 15% of U.S. primary lead smelting capacity at the time. Including this, Charles River reports that a total of 450,000 tons/year of capacity have closed since 1979 in the combined primary and secondary industries. A recent article in the trade press indicates that 20-25 percent of the currently operating capacity in the secondary smelting industry is doing so under the protection of Chapter 11 of the bankruptcy code.[14]

The battery industry has also undergone considerable consolidation[17], however as noted before, this has in part been the result of technological change for the production of new kinds of batteries (e.g. maintenance free, and with somewhat lower total lead content).

In the face of this experience, it is not unreasonable to liken an investment in the primary or secondary lead industries to a now-proverbial "riverboat gamble". A new investment in primary lead production capacity, in particular, represents a bet on lead demand and prices over at least ten to twenty years. A major consumptive use of lead, for gasoline additives, has already been greatly reduced in the U.S. and in the long run may be similarly reduced world wide. Since 80% or more of the lead going into batteries is ultimately recycled, the two thirds of lead "consumption" that now goes into batteries creates a quite persistent societal inventory of product. If the day ever were to come when non-lead battery systems began to be used for a substantial fraction of SLI batteries, it seems likely that the output of secondary smelters could supply all the lead required in other uses for quite a long while with little or no addition from primary production. On the other hand, if there were to be an appreciable conversion to diesel automotive power systems (requiring higher-capacity batteries with increased lead content) or if a substantial market were to develop for electric-powered vehicles relying on improved lead batteries, demand for lead could increase substantially.

If these market uncertainties create appreciable risks for new investment in any new lead production capacity, a project for investing in new capacity based on substantially new technology of course must overcome a further dimension of risk--that the new technology might not work as well as planned, or as soon as planned*. One important question that was not addressed in the CRA economic anaysis of the costs and benefits of implementing new technology was possible effects (positive or negative) on the efficiency of recovery of the economically important metal byproducts of lead smelting. Finally, given the prospect that even the new production technologies will not fully meet the 50 ug/m^3 permissible exposure limit, the requirement that occupational lead exposures be controlled as much as "feasible" adds a third dimension of risk.

In this situation it seems reasonable suggest that it may be in the general public interest to reduce the burden of risk now borne by the private sector. This might be done in part by a kind of joint negotiation process--bringing authorized representatives of the management and labor from the industries concerned together with EPA, OSHA, and other governmental entities as needed to work out a definitive agreement on hazard control and new technology development projects. To the extent that the general public may benefit from

o maintaining U.S. technical capability and comparative advantage in lead production technology

o maintaining access to substantial lead production within the country for possible national security needs it may be reasonable for there to be some general societal underwriting (such as loan guarantees) of the risks of developing new lead production technology.

---

*One indicator of the perceived risks of new technology in the primary lead industry is the following saying uttered by the former chairman of the board of a major company in the field on a recent visit to M.I.T.:

> "There are three ways to lose money: The fastest is gambling; the most fun is women; and the surest is new technology."

The bottom-line decisions facing the country on occupational lead regulation can basically be thought of as three-fold:

o What exactly will be required, and when?

o When will it be known with reasonable precision what exactly will be required, and when?

o What, if any, general societal support will be provided to reduce the risks of investing in new process sed in an explicit planning process that would bring together all of the interests concerned.

References for Section 3

1. Charles River Associates. *Economic and Environmental Analysis of the Current OSHA Lead Standard* Report to the Ocupational Safety and Health Administration, CRA Project No. 5356.60, September, 1982

2. Bureau of the Census, *1977 Census of Manufacturers*, August, 1981

3. Bureau of the Census, *Annual Survey of Manufacturers*, 1978-82

4. Ashford NA, Gecht RD, Hattis DB, and Katz JI: *The Effects of OSHA Medical Removal Protection on Labor Costs of Selected Lead Industries* Report to the U.S. Department of Labor under contract B-9-F-7-2831, M.I.T. Center for Policy Alternatives Report No. CPA-77/11, December 1, 1977

5. Mendez W, Hattis D, and Ashford NA: *Analysis of Available Evidence on Blood Lead-Air Lead Relationships Relevant to the Selection of a Permissible Exposure Limit for Lead in Air* Report to the U.S. Department of Labor under contract J-9-F-8-0044, M.I.T. Center for Policy Alternatives Report No. CPA-78-13, July, 1978

6. Mendez W, Priest WC, and Hattis D: *Calculation of Costs of Medical Removal Protection Provisions of the OSHA Lead Standard with Phased-In Removal-Return Triggers* Report to the U.S. Department of Labor under contract J-9-F-8-0044, M.I.T. Center for Policy Alternatives Report No. CPA-78-13, August, 1978

7. National Center for Health Statistics: "Blood-Lead Levels in U.S. Population" *Morbidity and Mortality Weekly Report* *31* 132-4, March 19, 1982

8. Annest, J.L. et al.: "Blood Lead Levels for Persons 6 Months-74 Years of Age: United States, 1976-80" NCHS *Advancedata* Number 79, U.S. Dept. Health and Human Services, Publich *Health Service*, Office of Health Research, Statistics and Technology, May 12, 1982

9. Breton, T.R. and Janney, Asa M. III: *The Relationship Between Gasoline Lead Usage and Blood Lead Levels in Americans: A Statistical Analysis of the NHANES II Data* Report by ICF, Inc. to the U.S. Environmental Protection Agency under Contract No. 68-01-5845; Joel Schwartz and Bart Ostro, EPA Project Officers, December, 1982

10. Hattis, D.: *Dynamics of Medical Removal Protection for Lead--A Reappraisal* Report to the National Institute for Occupational Safety and Health under Purchase Order #81-2714, M.I.T. Center for Policy Alternatives Report No. CPA-81-25, September, 1981

11. Riggs, D.S.: *The Mathematical Approach to Physiological Problems--A Critical Primer* Williams and Wilkins Co., Baltimore, Md., 1963, especially chapter 7, "Transfer of Substances Between Biological Compartments. Simple Diffusion." pp. 168-192

12. Anon.: "OSHA Raises Engineering Control Level, Extends Compliance Period in Draft Rule." *Occupational Safety and Health Reporter* Bureau of National Affairs, April 7, 1983, pp. 941-2

13. Parkinson, G.: "New Smelting Methods Aim to Get the Lead Out." Chemical Engineering pp. 93-4, May 19, 1980

14. Schroeder, N.: "Secondaries to Tough it Out" Am. Metal Market April 21, 1983, p. 4A

15. Botta, M.: "Lead's Problems Weighty" Am. Metal Market April 21, 1983, p. 3A

16. Anon.: "Lead Duty OK Expected from Gov't" Am. Metal Market May 11, 1983, p. 1

17. Botta, M.: "Consolidation Helps Cut Producer Costs" Am. Metal Market April 8, 1983, p. 8

18. Harris, H.E. et al.: "Respirator Usage and Effectiveness in Bituminous Coal Mining Operations" Am. Ind. Hyg. Ass. J. 35 159-55, 1974

19. Smith, T.J. et al: "Inhalation Exposure of Cadmium Workers: Effects of Respirator Usage" Am Ind. Hyg. Ass. J. 41 624-9, 1980

20. Edward Baker, Harvard University, personal communication.

21. Chamberlain, A.C.: "Effect of Airborne Lead on Blood Lead" Atmospheric Environment 17 677-92, 1983

22. Braun K.O., Knutson G.W., and Caplan K.J.: "Supplementary Report to Feasibility and Cost of Lead-in-Air Controls in the Lead-Acid Battery Industry" for Charles River Associates, Inc., Project 486-005, February, 1983

23. Leidel N.A., Busch K.A., and Lynch J.R.: "Occupational Exposures Sampling Strategy Manual" DHEW (NIOSH) Publication No. 77-173, January, 1977

Appendix A

EMPLOYEE PROFILE AND EXPOSURE DATA

1. For each of your company's plants, please provide the following information:

	1977	1978	1979	1980	1981
a) total workforce					
b) production workforce					
c) lead-exposed workforce					
d) lead-exposed new hires					
e) lead-exposed terminations					

2. For each of your company's plants, please provide the number of employees in the following air lead ranges without regard to respirator use on an average production day in the last year:

Air Lead Range	Number of Employees
<30 ug/m^3	
30-50 ug/m^3	
50-100 ug/m^3	
100-150 ug/m^3	
150-200 μg/m^3	
>200 ug/m^3	

3. Within each job classification or group of employees exposed to similar exposures and sources, what are the duration and frequency of exposure to lead, the typical time-weighted average (TWA) concentration of lead, and the reasons for variability in the TWA exposure (e.g., differences between shifts, seasonal variation)? If respirators are worn, specify the type and percentage of time worn.

4. For each of your company's plants, please provide information on the distribution of blood lead levels by calendar quarter since 1979:

	<40	40-49	50-59	60-69	70-79	>80
1979						
1						
2						
3						
4						
1980						
1						
2						
3						
4						
1981						
1						
2						
3						
4						
1982						

5. If you are aware of any confounding variables that have affected the rate of decline of employee blood lead levels, please identify them and show their effects. Examples of such variables might be the length of employment in a lead exposure area, process or work practice modifications that substantially changed employee exposure either through inhalation or ingestion, and seasonal variation in production.

6. For a sample of employees who have been exposed to a relatively constant air lead level and for whom personal sampling (as opposed to representative sampling) records are available, please provide the following information by individual:

a) employee identified by sex and job tenure
b) job classification
→ c) air lead levels and dates of sampling (estimated actual exposure if respirators were used and type of respirator)
d) blood lead levels and dates of sampling
e) ZPP levels and dates of sampling
f) other biological test results, including hemoglobin and hematocrit, and dates of sampling
g) frequency and duration of exposure

7. Please provide any available information on the particle size distribution and solubility of lead compounds to which employees are exposed.

8. Please provide any available information on the extent to which ingestion of lead resulting from personal hygiene practices compared to airborne lead exposures contributes to exposures. If possible, please quantify your answer.

9. If you have any other studies of air-to-blood lead correlations available (e.g., in-plant, retirees, strikers), please provide this information.

10. Please provide the following information by job classification for each employee medically removed since 1979:

a) date of removal
b) blood lead level at removal
c) place of removal and air lead level, if transferred within the workplace
d) monthly rate of decline of blood lead level
e) date of return (or reason why never returned)
f) blood lead level at return
g) job tenure
h) wage rate in pre-removal position
i) wage rate of transferred position
j) estimated cost of training replacements

11. What is the total number of positions where air lead levels are below 30 ug/m^3? At any given time, how many of these positions are available for MRP transfer? Explain any limitations that may be placed on the employer's ability to use these positions for MRP transfer.

12. Describe any special programs conducted to limit further exposure of employees whose blood lead levels are approaching the level that would require medical removal.

13. If you have any studies concerning the rate of decline of blood leads for workers removed from lead exposure, please provide this information.

Reproduced from
best available copy.

APPENDIX B

APPENDIX B

New Direct Smelting Technology as Part of an Overall Control Program for Worker Lead Exposures in the Primary Lead Smelting Industry--Engineering Considerations, Costs, and Economic Feasibility

B1. Introduction and General Description of Alternative Technologies

One of the intriguing possibilities raised by the Charles River report was that new smelting technology could substantially displace the two largest sources of lead emissions in primary smelting--the sinter machine and the blast furnace. Combined, these two units are responsible for approximately 69% of current total lead exposures in the principal primary smelting plant studied by CPA (Table B.1-A). These areas appear to be responsible for an even larger proportion of total exposure (78%) in a second primary smelter (Table B.1-B) although in this case data on the exposures of personnel working outside the smelter itself are not available for an exact comparison.

This possibility could make an interesting case study of the comparative costs and benefits to society of encouraging two alternative general strategies of emission abatement:

(1) Traditional "end-of-pipe" control technology has historically consisted of physical enclosure and ventilation systems to remove lead after it has been generated in the workpplace environment. Such systems clearly represent the most obvious and direct approach for emissions control, but just as clearly, costs are incurred by the industry with no short term benefits other than compliance with emissions standards (and such other effects of exposure reduction as reduction of MRP costs).

Table B1-A
Exposures in a Model Primary Lead Smelter by Plant Area

Plant Area	No. Workers	Ave. Air Levels (ug/m^3 (1981)	Total Exposure* (person-ug/m^3)	% Total Exposure
Materials handling	34	348	11,833	6.2
Sinter Plant	44	1,816	79,884	41.8
Furnace Area	68	767	52,187	27.3
Dross Plant	28	748	20,932	11.0
Refinery	90	140	12,587	6.6
Baghouse	15	204	3,055	1.6
Yard and Maint.	210	about 50**	about 10,500	5.5
TOTAL	489	about 390	about 191,000	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.2 (pp. C-79 to C-84) of the Charles River Report.

**Estimate from page F-55 of Charles River Report

Table B1-B

Exposures by Plant Area in a Second Primary Lead Smelter

Plant Area	No. Workers	Ave. Air Levels (ug/m^3 (1981)	Total Exposure* (person-ug/m^3)	% Total Exposure
Materials handling	35	170	5,950	3.6
Sinter Plant	36	1,775	63,887	39.1
Furnace Area	41	1,550	63,570	38.9
Dross Plant and Refinery	62	298	18,501	11.3
Baghouse and Acid Plant	26	448	11,635	7.1
Other (headquarters staff, etc.)	about 200	Exposures not given		
TOTAL (excluding (headquarters)	200	818	163,543	100

*Computed by multiplying the numbers of workers in individual job classes by reported average exposures in Table 3.2 (pp. D-63 to D-68) of the Charles River Report.

(2) Process design change involves redesign of the process which is responsible for formation of pollutants. By approaching the system as a whole, it may be possible to arrive at a more cost-effective solution than by addressing only one portion. Innovative redesign and reconstruction of the entire production process may result in substantial savings in labor and energy costs, as well as a decreased quantity or strength of waste produced.

Conventional existing smelting involves "roasting" lead sulfide ore to lead oxide, then reducing it by carbon to metal in a blast furnace. A series of refining steps then remove a number of impurities from the crude lead(including economically important byproducts, such as silver) .

Major features of concern in sinter/blast furnace process include:

o Major emissions of lead, particularly in materials handling, sintering and the blast furnace,

o Inefficient use of energy; the fuel value of the sulfur in the ore is wasted

o Expensive coke is required to reduce lead oxides to metal

o The sinter machine is major maintenance problem; downtime can be up to 40%, leading to increased labor costs and high exposure levels for maintenance workers.

In contrast to this, "direct smelting" processes combine the roasting of lead sulfide ore with the smelting system in a single reactor. Major advantages of direct smelting processes over the traditional system include:

o Reduced emissions in several plant areas

o The fuel value of the sulfur in the ore is used

o The process uses coal rather than more costly coke

o Minimal materials handling is required (no sinter and slag recycle)

o Maintenance requirements are reduced; making the process less labor intensive

o Because there are fewer total workers, and especially fewer highly-exposed maintenance workers, there is less overall worker lead exposure

- The offgas from the process has a relatively hgh SO2 concentration in the offgas, resulting in easier synthesis of by-product sulfuric acid, a greater quantity and higher quality of acid.

The Charles River report considered several non-smelting and four different new "direct" smelting processes for use in the primary lead industry:

- Several "Hydrometallurgical" non-smelting processes involving the use of chloride salt leaching have been researched. In the opinion of Charles River, at this time technical difficulties (e.g. equipment corrosion and transport of chloride materials) remain to be solved at an acceptable cost before such processes are commercially viable. Others may well be more optimistic about the long term potential of these intrinsically less-polluting alternatives.

- The Queneau-Schumann-Lurgi (QSL) direct smelting process involves a horizontal cylindrical reactor in which smelting reactions occur in a liquid bath. Both oxidizing and reducing sections are contained within the reactor, with lead and slag flowing countercurrent to each other. Thus, both low-sulfur lead and low-lead slag are produced.

- The KIVCET direct smelting process involves flash-smelting, to burn out the iron and sulfur content of the concentrate while it is suspended in an oxidizing atmosphere. Pure oxygen is used, so that complete oxidation into a slag phase is accomplished. An electric furnace attached to the smelting shaft subsequently reduces the slag.

- The Outokumpu direct smelting process is similar to the Kivcet process, except the furnace geometry differs and enriched air is used rather than pure oxygen. Thus, only moderate reduction is required in the slag cleaning furnace, which is connected to the smelting furnace by covered launders.

- The Top Blown Rotary Converter direct smelting process involves batch rather than continuous operations. The vessel reactor is rotated slowly to mix the contents and to protect the exposed refractory lining while oxygen and fuel are blown onto the bath surface. Smelting and slag cleaning are performed sequentially.

B2. Description of Conventional Control Technology

Below we outline the conventional control technology described in the Charles River Report as available to reduce worker exposure to lead emissions in a 225,000 ton/year capacity primary lead smelter to more closely approach the 50 ug/cubic meter occupational exposure standard.

(It should be noted that the labor representative, in reviewing this part, suggested several additional conventional controls that he considered to be feasible--particularly in the form of additional isolation of the worker in control booths or self-contained cabs.) As will be seen, most of the conventional control technology involves simple physical containment systems such as covers, hoods and ventilation rather than basic process change as in the redesigned smelter system. Many of the systems include capture and recycle of fugitive dust, which is a major source of worker exposure. Thus, most systems would function to reduce worker exposure as well as general air emissions. Each of the paragraphs below cover a particular set of operations at a primary smelter--describing first the operations themselves and then the available controls for an existing smelter. In most cases, the corresponding controls for a retrofit smelter would be essentially the same, except smaller in scope in some areas. The major difference results from elimination of the sinter/blast furnace area, a major emissions source.

The paragraphs below are arranged in order of their appearance in the overall processing sequence to produce lead bullion.

Materials receipt and storage: Concentrate, fluxes and coke make up the bulk of materials to be received and stored. The materials are received by rail, weighed, sampled and stored. Concentrate that is not needed immediately is unloaded by crane with a clamshell bucket and placed in yard storage. Coke is unloaded by bottom-discharge into large storage bins located beneath a trestle. Excess finished sinter is also bottom-dumped at trestle for temporary storage prior to use in blast furnace. Temporary storage is also provided for other materials that are reccled through the smelter: sinter (the concentrated ore after it is oxidized in the sinter machine); slag (the impurity-bearing layer of rock-like material that floats on top of the metal layer during smelting); and recovered flue dust. The rail facilities also handle portions of the product and byproduct transport.

o Railroad cars: Covers would be provided on gondola cars bearing concentrated ore between the mine and plant to control moisture and eliminate dust blown from cars.

o Rail car unloader machine: Equipment would be added to improve flow of concentrates, baghouse fume and dusts. Also, workers operating the unloader machines would spend 2 to 3 hours per shift in a controlled environment booth.

o Covered stockpiles: Construct building to contain storage piles of concentrate, and adjust method of loading and retrieving.

Sinter plant: A multibelt conveyor system transports concentrates, fluxes, slags, dusts and reverts from rail car station hoppers to holding bins in the sinter plant mixing area. Return slag and other plant reverts are also deposited in bins. Feeders under the bins regulate the rate of discharge of each material to a common collecting conveyor belt, which delivers the mixture to a mixing and crushing operation. The crushed material is conveyed to a pelletizing drum, which moistens and coats the mixture prior to sinter machine feed.

o Conveyors and storage bins: Enclose belt conveyors and transfer points. Use air blasters to reduce manual lancing. Modify bin geometry to improve materials flow. Pass exhaust gas through baghouse.

o Sinter machine: Enclose and ventilate feed system, use wet scrubbing unit for removal of particulates from the exaust gas.

o Sinter return conveyor belt system: Enclose conveyor belt system and transfer points. Ventilate transfer points, use wet scrubbers.

o Finished sinter system: Enclose and ventilate conveyors and transfer points. Clean the return conveyor belts.

o Rail car transfer: Enclose and ventilate entire rail car charging area. Place operator in a control booth.

o Makoup air: Ventilate and filter air for sinter machine buliding.

o Sinter machine draft control: Eliminate "puffing" of the sinter machine hood.

Blast furnace area Finished sinter, coke and material recycled from later "drossing" steps in the production process are conveyed to storage bins in the blast furnace plant. The feed materials are then transferred to shuttle conveyors which distribute the charge along the length of the furnace. The alternate layers of sinter and coke descend through the blast furnace as the underlying burden is smelted and withdrawn. Air is blown in through rows of holes (tuyeres) near the bottom of the furnace. Slag is "tapped" (drawn off from the top of the molten metal) continuously, and is granulated into fine particles in a slurry form. The slurry is dewatered, and transferred for recycle or to the slag dump. Settled bullion is tapped from the bottom of the furnace and transferred to the drossing prossess (see below).

o Materials feeding (sinter and coke): Enclose and ventilate belt conveyors and transfer points. Use new baghouse to treat ventilated air.

o Charging area: Enclose and ventilate area.

o Furnace tuyeres: Modify tuyere air distribution and hardware used during punching. Develop and adapt automatic punchers for furnaces.

o Tapping lead and slag: In each furnace, enclose siphon tap in an improved hood and ventilate. Liquid slag overflows to water granulation system. Liquid lead flows into large pots for transfer to dross department. Lead vapor is emitted from pots. Establish "clean air island" for lead tapping system, provide ventilation, cleaning and baghouse capacity.

o Blast furnace draft control: Add automatic controls to reduce air-lead levels and improve baghouse capacity utilization.

Dross Plant Blast furnace bullion is poured into large, stirred drossing kettles to remove impurites. Additions of flux, coke and soda ash are required. The kettles cool, and a copper-rich dross is skimmed and charged to a reverberatory furnace for smelting. The partially decoppered bullion is further refined.

- o Bullion pots: Transfer liquid lead from blast furnace to dross plant at lower temperture to reduce vapor pressure. Add covers to pots.
- o Drossing: Cover and ventilate kettles.
- o Ventilation system: Provide system for entire building.

Refinery Lead bullion is further refined in a multi-step process in a large number of heated, stirred kettles. Lead must be transferred between kettles by bailing, and recycle of drosses is necessary. Silver and other materials are removed.

- o Background: Improve building ventilation.

- o Kettle operation: Install hoods,covers and ventilation system. Provide baghouse.

- o Skimming: Provide special hoods and ventilation system to contain and transport skimmed material from caustic drossing operation.

- o Hopper dust control: Provide hood, exhaust and baghouse.

- o Retort: Provide ventilation system to collect, store and charge zinc-silver material to retort furnace. System includes hoods, bins, ventilation system and dust collection unit.

Offgas system and baghouses Dust and fume captured from sinter machine, blast furnaces and ventilation system is transferred into railroad cars for recycle to materials handling system.

- o Cleaning the filter bags ("pugging"): Improve system for removing dust and fume from baghouses.

Central Vacuum System Install stationary vacuum cleaning system to serve areas where dusts accumulate.

Worker exposures under this control program will be outlined later in

Section B5.

B3. Costs of a Direct Smelting Replacement vs. Conventional Control Technology

In contrast to the conventional control program outlined above, Charles River also analysed the costs and exposure reductions obtainable by a program in which the QSL process would be substituted for the sinter machine and blast furnace of a conventional primary lead smelter. The other portions of the lead refining process would remain essentially unchanged, and the conventional control programs for those portions of the plant would also be similar.

Table B2 provides a breakdown of capital, operation and maintenance costs, and number of personnel required for the process areas described above. Not included in this table are the capital costs of the 225,000 tons/year QSL direct smelter system itself, which are detailed in Table B3. (We made this separation to make clear that the conventional emissions/ventilation controls for the direct smelter are less than the controls required for the existing system).

All estimates were obtained from the Charles River report. Capital and Operation and Maintenance costs shown are for the emission control systems only, while personnel requirements are for regular plant operations. Alternative A involves installation and operation of control systems for an existing sinter/blast furnace type smelter. Alternative B involves retrofitting the same smelter with a new QSL direct smelting furnace, and installing and operating the necessary control systems. The table demonstrates that the direct smelting system provides a 45% capital cost savings and a 43% operation and maintenance cost savings for control systems over the existing technology smelter. In addition, labor requirements for regular plant operations in these areas of the plant are decreased by 22%.

In interpreting Charles River's figures, we have assumed that labor costs were not included in the operation and maintenance costs listed in theses columns. This is because the difference in total "Control Operation and Maintenance Costs" ($1,734 - $1,017) in the Charles River analysis is enough to account for only 24 workers, when it should account for 114 workers if "Control Operation and Maintenance Costs" include labor. Also, in summarizing incremental retrofit vs. control systems with existing smelting technology costs, Table 4.2 of Appendix F lists both incremental control Operation and Maintenance and incremental labor costs, adding both to other incremental costs such as capital and production material costs to arrive at a total incremental cost.

"Control Operation and Maintenance" here is apparently regular operation and maintenance costs, excluding labor, such as materials and supplies for cleaning, replacing minor parts such as belts for fans, painting, etc. Since it appears that a general rule of "10% of capital cost equals annual Operation and Maintenance cost" was used in many of the estimates, and that this rule normally includes labor costs, these estimates are probably somewhat higher than necessary.

Table B2
Comparison of Compliance Costs for Existing Technology and New-Technology Replacement for Emissions Controls for a 225,000 Short Ton/Year* Primary Smelter

(All cost figures are in thousands of 1982 dollars)

	Alternative A Controls on existing sys.			Alternative B Controls on direct smelter system		
Control Technology Item	Initial Capital	Op. and Maint.	No. Pers-onnel	Initial Capital	Op. and Maint.	No. Pers-onnel
Materials Rec't and Storage			34			20
Railroad cars	605	66.9		605	66.9	
Rail car unloader	178.4	9.1		178.4	9.1	
Covered stockpiles	740	42		500	30	
Controlled cab	40	4		40	4	
Sinter plant			44			19
(maintenance)			22			
Conveyors & storage bins	2,220	101		1,500	70	
Sinter machine feed	585	48.4				
Sinter machine dusty air	140	7				
Sinter machine return conveyor	370	22.4				
Finished sinter system	659	49.5				
Rail car transfer	546	47.5				
Makeup air	855	192.2				
Sinter machine draft control	80.6	3.4				
Control booth	10	1				
Blast Furnace Area			68			49
Material feed system (sinter & coke)	1,231	86.2				
Charging area	352	18				
Furnace tuyeres	500	50				
Tapping lead & slag	218	38.8				
Blast furnace draft cont.	34.3	3.1				

(continued on next page)

*A short ton is 2000 lbs. A long ton (metric ton) is 1000 kg, roughly 2200 lbs.

Table B2, Continued

	Alternative A Controls on existing sys.			Alternative B Controls on direct smelter system		
Control Technology Item	Initial Capital	Op. and Maint.	No. Personnel	Initial Capital	Op. and Maint.	No. Personnel
Dross plant (& refining)			118			118
Drossing	721	51.2		721	51.2	
Vent. system	1,588	268.9		1,588	268.9	
Controlled cab	10	1		10	1	
Refinery						
Background (specify)	1,802	277.2		1,802	277.2	
Kettle operation	961	58.4		961	58.4	
Skimming	75.9	3		75.9	3	
Aurora hopper dust cont.	752	60.8		752	60.8	
Retort	634	66.4		634	66.4	
Offgas Sys. & Baghouse			15			21
Pugging	1.007	65.4				
Yard crew			75			52
Maintenance			135			118
Central vacuum sys.	1,301	90.8		700	50	
Total	18,216	1,734	511	10,067	1,017	397

Table B3

Additional Capital Costs to Replacement Direct Primary Smelter

(In thousands of 1982 dollars)

****

QSL reactors, feed. system, off-gas handling	88,000
Reactor bldg, cranes, platforms, vent, services	10,000
Acid plant	22,000
New & revised mat. handling equipment	5,000
Total	125,000

B4. Overall Economic Comparison Between the Alternatives

Table B4 provides a comparison between raw materials requirements and byproduct quantities for a 225,000 ton/yr capacity sinter/blast furnace system and a QSL direct smelting system. All figures are taken from the Charles River report, Appendix F. These figures are for the actual smelting process only, and do not include materials costs for other phases of the refining process, since they are not impacted by the retrofit. Lead bullion, slag and matte quantities are provided to demonstrate that the amount of these materials produced is essentially the same in each process.

Byproduct income is provided only for acid, since this is the only material whose quantity or quality differs between the two processes. In the original Charles River report, the analysis assumed that greater revenues would result from the higher quality "white acid" that would be produced in the QSL direct smelting process, and that greater quantities of acid would result from the redesigned plant than from the conventional sinter/blast furnace process. Since the version of Charles River report we have was submitted, this conclusion has reportely been revised, and that portion of Table B4 may therefore not reflect the final assessment.

Table B4

Comparison of Material Inputs and Outputs to the Conventional Smelting and Replacement Direct Smelting Processes

	Alternative A Controls on existing system			Alternative B direct smelter replacement and controls		
Raw Materials	ton/day	$/ton	$1000/yr	ton/day	$/ton	$1000/yr
Reductant	145 (coke)	150	6,525	100 (coal)	50	1,500
Flux	117	20	702	110	20	660
Oxygen				350	25	2,625
Lead conc.	1,000			1,000		
Power	18,400kw	5c/kwh	6,625	11,100	5c/kwh	4,396
Subtotal			13,852			9,181

Products	ton/day	$/ton	$1000/yr	ton/day	$/ton	$1000/yr
Lead Bullion	712			712		
Acid	221	5	332	468	20	2808
Slags	239			250		
Matte	21			20		

Table B5 combines the results of Tables B2, B3 and B4 to provide a summary of control costs and costs affected by the installation of the new smelting technology. Taking capital and Operation and Maintenance costs associated with emission control devices and subtracting operational benefits (material and labor savings and increased income from the sale of byproduct acid) gained by using direct smelting, the resulting SUBTOTAL shows that for a given smelter, direct smelting has operational SAVINGS of 1.82 cents per pound of lead produced. Clearly, if a new smelter is to be constructed in Missouri (as expected by Charles River) or anywhere else, the operational savings alone would mandate construction of a direct smelting system rather than a sinter/blast furnace system. The TOTAL line adds the cost of replacing the blast furnace and sinter machine of an existing smelter with a new QSL direct smelter. Thus, for an existing 225,000 ton/year plant., the cost of compliance using conventional control systems is 0.93 cents per pound while the net cost of replacement with the QSL direct smelting system is 1.90 cents per pound. The latter estimate, however, should be considered highly sensitive to CRA's tentative estimates of the labor and energy savings of the direct smelting system. Other important factors in the analysis are the interest rate and depreciation assumptions. Finally, CRA did not include any factor for savings of MRP costs. In the light of the decreased exposure of the replacement system, (see below) this may well be important.

Table B5
Summary of Economic Costs in $1000/year

COST	COSTS Alternative A Existing Smelter	Alternative B Direct smelter retrofit
1) Control system capital cost * assuming 12%/yr	2,439	1,348
2) Control system Operation and Maint.	1,734	1,017
3) Materials (savings)		(4,671)
4) Labor (savings)		(3,420)
5) Acid product (increased income)		(2,476)
SUBTOTAL	4,173	(8,202) (savings)
New Direct Smelter Replacement Capital Cost*		
assuming 8%/yr		12,731
assuming 12%/yr		16,735
assuming 16%/yr		21,084
TOTAL COST (assuming 12%)	4,173	8,533

* Lifetime for both the control system equipment and the retrofit smelter were assumed to be 20 years. See Charles River report, p. F-65. A range of interest rates (8%,12%,16%) was chosen, although 12% was taken as an average representative value.

Table B6 provides a general summary of the cost structure for the primary lead industry, as best we can determine it from publicly available sources. This is helpful in order to place emissions compliance costs in the proper perspective. Since the corporations which own the primary lead smelters are integrated to a large degree and highly diversified, it is difficult to obtain detailed information on the cost structure of the industry. Therefore, the figures below are intended to provide only a rough estimate of relative costs of major items, rather than a precise breakdown. Detail is provided only for those items whose cost differs between the two alternatives.

A major observation is that income from the sale of lead bullion itself appears to account for only one-third of total income for a primary lead smelter. Other income is the result of sale of byproducts described below. Thus, while lead smelting may appear to be only marginally profitable or non-profitable if lead alone is considered, it may in reality be quite profitable when the total cash flow is examined. Clearly, control costs should NOT be compared only to the price of lead, but rather should be taken in the context of total cash flow.

Table B6

Overall Cost Structure for a 225,000 Ton/Year Primary Smelting Plant

	Alternative A		Alternative B	
Cost Item	$1000/yr	c/lb*	$1000/yr	c/lb
Fixed capital	17,830	3.96	17,830	3.96
Control capital	2,439	0.54	1,348	0.30
Control O and M	1,734	0.39	1,017	0.23
New smelter cap.	0	0	16,735	3.72
Materials				
Ore	267,200	59.38	267,200	59.38
Flux	702	0.16	660	0.15
Coke or coal	6525	1.45	1500	0.33
Power	6625	1.47	4396	0.98
Oxygen	0	0	2625	0.58
Other materials#	126,508	28.11	126,508	28.11
Labor				
Payroll	26,650	5.92	23,938	5.32
Soc.Sec.	1,908	0.42	1,714	0.38
Emp.Ben.	4,343	0.97	3,900	0.87
Rental	577	0.13	57	0.13
Misc.+	13,500	3.00	13,500	3.00
Total Cost	476,541	105.90	483,448	107.44
Income Item				
Pb product	164,250	36.50	164,250	36.50
Acid	332	0.07	2,808	0.62
Other materials#	344,858	76.64	344,858	76.64
Total	509,440	113.21	511,916	113.76

* $/year X 1/225,000 tons/yr X 1/2000lb/ton X 100c/$ = cents/lb

#"Other materials" refers to costs or benefits for non-smelting operations for further lead refining and recovery of byproducts such as copper, zinc, silver, gold, bismuth. For a detailed discussion, see "Explanation of Basis of Estimates used in Table B5"

+ "Misc." includes compensation of officers, bad debts, unemployment insurance taxes, insurance, telephones, permits, advertising, royalties, research, etc.

Explanation of the Basis of Estimates Used in Table B5

1) Production Capacity of Major Smelters: used to determine percentage of "Total Primary Lead Industry" figures attributable to a 225,000 ton/year primary smelter.

2) Ore Prices: used to determine average price of ton of ore, and cost of concentrate.

3) Labor Costs: used to determine components of labor costs to industry, labor costs attributable to a 225,000 ton/year plant, and decrease in labor costs due to use of direct smelting technology.

4) Income from other materials: used to determine income to industry from sale of byproducts.

5) Other materials costs:used to determine the cost of materials not directly involved in the actual smelting process, or not included in the Charles River report because they are not affected by a change in smelting technology.

Production/Capacity of Major Smelters (Ref.1)

Company production	'82 Est.Cap. short tons	'80 Production short tons	% of Plant capacity	% of Total capacity used	% of Total '80 available
ASARCO	266,000	175,600	66	42	34
AMAX	140,000	132,182	94	22	26
ST.JOE	230,000	208,651	91	36	40
TOTAL	636,000	516,433	81	100	100

For 1981, a 225,000 ton/year production plant accounts for 225/551 or 40% of total production. Therefore we assume a value of 40% for the percentage of "industry-wide total" figures for costs, personnel, and benefits attributable to a 225,000 ton/year plant.

Assume Ore initially with 5% lead content(Ref.5&8), requiring milling to form a concentrate of 75% lead. (Ref. 5)

ORE PRICES

MINE	Co.	$Value/ ton of ore (1974 $)	'74 ore tonnage	% of total	'74 Lead Prod. tonnage	% of'74 Lead Prod.
Leadville	Asarco	57.58	163,226	1	6,400	1
Groundhog		47.33	126,147	1	2,075	0.3
Buick	Amax	48.17	1,560,000	11	186,647	28
Fletcher		14.73	5,048,133	37	247,494	37
Balmat/ Edwards	St. Joe	37.23	1,232,462	9	3,076	0.5
Magmont& Ozark		18.60	2,440,300	18	141,880	21
All others		39.15	3,188,494	23	84,190	13
TOTAL			13,758,762	100	671,762	100

Average Ore Price equals weighted average = sum of (% X price)

ASARCO	(0.01 X 57.58) + (0.003 X 47.33)	= 0.72
AMAX	(0.28 X 48.17)	=13.49
St.Joe	(0.37 X 14.73) + (0.005 X 37.23)	= 5.64
Mag/Ozark	(0.21 X 18.60)	= 3.91
All others	(0.13 X 39.15)	= 5.09
Total		$ 28.85/ton

$28.85/ton of ore (in 1974 dollars)
X 439.0/212.8 (convert to 1981 dollars)
X 15 tons ore/ton concentrate
X 1000 tons concentrate needed/day
X 365 days/yr
X .82
= $267,200,145 /year for lead ore in 1981 dollars

LABOR COSTS
Total Primary Lead Industry

Year	Number of Employees						Cost in million $	
Payroll other	legal	Social rqmts.	Security & Benefits		Employee	Total		
			% of total		% of total		% of total	
1976	3,200	43.5	81%	3.1	5.8%	7.1	13.2%	53.7
1975	3,100	38.2	81%	2.7	5.7%	6.2	13.2%	47.1

Check $30,000/yr per worker in CRA report:
$11.44/hr X 2080 hr/yr = $23,795/yr per worker for payroll only
23,795/30,000 = 0.79, which is approximately equal to 81% , so $30,000 assumption is OK.

Assume average worker wage = production worker wage
Number of personnel needed for alternative A = 0.40 X 2,800 = 1120
Number of personnel needed for alternative B = 1120 - 114 = 1006

Income from "Other Materials"

While 99.9% pure lead bullion is the "primary" product of this industry, sale of other materials produced in the smelting operation contribute significantly to total income. These materials include antimonial lead, 100% of domestic bismuth produced, 56% of domestic antimony produced, zinc,silver, tellerium, copper, gold and sulfur.

From U.S. Department of Commerce, 1983 Industrial Outlook, 1983: For 1980, Value of Shipments (value of all products and services sold by the primary lead industry) was 1,592.7 million dollars, total primary lead production was 607,000 short tons, and producer price was 42.5 cents per pound. Thus, total industry income from the sale of lead alone is:
607,000 tons X 2000 lb/ton X $0.425/lb = $ 515,950,000

Percentage income from lead is:
$ 515,950,000 / $ 1,592,700,000 = 0.32 or, roughly one-third

Using this same method for 1981:
551,000 tons X 2000 lb/ton X $0.365/lb = $ 402,230,000 lead income
Percentage income from lead is:
$ 402,230,000 / $ 1,273,600,000 = 0.32 or, roughly one-third

"Other Materials" Costs

Materials costs provided by the Charles River report included only those necessary for the actual sinter/blast furnace or direct smelting operation, and emphasized differences in materials requirements for the two alternatives. Not included were materials costs for other phases of the total refining process, and other costs common to both alternatives. In order to arrive a a figure for these costs, "Cost of Materials" figures from Ref. # 3 and # 6 were used. A stable ratio of 0.8 between "Cost of Materials" and "Value of Shipments" for 1972 and 1977-80 was obtained. This ratio was applied to the estimated "Value of Shipments for 1981 to arrive at a total industry figure for "Cost of Materials". This figure was then multiplied by 0.40 to arrive at the cost for a 225,000 ton/year plant, and the known ore and other smelting materials were then subtracted.

The following is a brief description of the "other materials" necessary in the non-smelting phases of operation. A variety of materials is needed, along with significant amounts of natural gas or oil for heat and electricity for power. For a detailed description of each process, refer to Reference # 5, pages 259 - 332.

PROCESS	Materials Needed
Ore Concentrating	Water, electricity,wastewater treatment costs
Contact Sulfuric Acid Plant Sulfur-rich offgas from the produce sulfuric acid.	Clean water (possibly de-ionized), a catalyst (vanadium pentoxide), cooling water, electricity, wastewater treatment
Slag Fuming Furnace Recovers metals in slag	Coal, cooling water, wastewater treatment
Drossing Initial lead bullion refining step	Sulfur to remove copper, coal of coke, natural gas for heat, electricity
Dross reverb. Furnace	Pig iron, silica, limestone, gas or oil for heat
Cadmium recovery	Oil, gas, electricity for heat
Reverb. Softening	Litharge, coke or coal, electricity,gas or oil

Antimony Recovery	Coke or charcoal, soda ash or silica, gas or oil, electricity, cooling water
Desilverizing	Zinc, gas or oil, electricity
Retort	Electricity
Cupelling	Sodium nitrate, silica flour, gas or oil cooling water
Dezincing	Gas or oil, electricity. chlorine or anhydrous sodium hydroxide
Debsmuthizing	Calcium, magnesium, antimony or organic compounds, gas or oil, electricity
Bismuth refining	Chlorine gas, caustic soda flux, charcoal, gas or oil, electricity
Final Refining and Casting	Caustic soda, sodium nitrate, water, gas or oil, electricity, wastewater treatment

B5. Overall Effects of the Control Alternatives on Exposures and General Conclusions

Table B7 provides a summary of the effect on total lead exposure of the two alternative systems. Neither system can be expected to achieve full compliance with a worker exposure standard of 50 ug/cubic meter. However, decreased numbers of personnel required and decreased average air lead exposures for specific portions of the plant yield a significant difference in the overall total lead exposure between the two alternatives. "Total lead exposure" is defined here as the weighted sum of air lead exposures, or the sum of (number of workers in area X average exposure in that area).

While both the "existing smelter with controls" and the "Replacement direct smelter with controls" alternatives provide a substantial decrease in total lead exposure from the existing smelter with current controls, there is an equally substantial difference between the two alternatives. Controls on the existing smelter result in a 54% decrease in total plant lead exposure. Controls on retrofit smelter result in a 76% decrease in total plant exposure, from existing control levels. So, the retrofit smelter system results in 56% lower total lead exposure from the existing system with future conventional controls.

In conclusion we find that:

o The net before tax cost of compliance for existing smelter + controls is about 0.93 cents/lb.

o The net before tax cost of compliance for retrofit smelter + controls = 1.90 cents/lb.

o The resultant worker exposure total in the retrofit + controls system is only roughly one-half that of the existing + smelter controls system.

Table B7
Total Lead Exposure by Plant Area
(in person-micrograms per cubic meter)

Plant Area	Existing Smelter With Current Controls	Existing Smelter With Future Conventional Controls	QSL Replacement System With Modified Conventional Controls
Materials handling	11,800	5,500	3,200
Sinter Plant	79,900	26,300	5,800
Furnace area	52,200	25,200	16,200
Dross Plant	20,900	15,600	15,300
Refinery	12,600	8,600	8,000
Baghouse	3,100	2,300	1,100
Yard & Maintenance	na	na	(3,100)
*TOTAL	180,500	83,500	46,500

(Note: Totals may not exactly add due to rounding)

Thus, the net cost of installing a retrofit direct smelter and controls is roughly twice that of installing controls only at an existing sinter/blast furnace plant, and the resulting total worker exposure is cut in half. The resulting worker exposure would still not be in full compliance with the 50 ug/m^3 air standard, but it would be significantly closer than with the use of conventional controls. Another important fact is that these are BEFORE TAX figures. Investment credits and pollution control credits would favor the replacement alternative because of its high capital cost. In addition, medical removal cost savings, which would also favor the direct smelting replacement alternative, are not included.

References for Appendix B

1. Charles River Associates, Economic and Environmental Analysis of the Current OSHA Lead Standard, submitted to the Occupational Safety and Health Administration, Washington, D.C., 1982

2. U.S. Dept. of Congress, 1983 Industrial Outlook

3. 1977 Census of Manufacturers, "Smelting and Refining of Non-ferrous Metals and Alloys" MC 77-1-22C, Bureau of Census

4. Wise, Kenneth Tod, The Effects of OSHA Regulations on the U.S. Lead Industry: An Economic Impact and Econometric Modeling Analysis, Ph.D. Thesis at MIT, 1978

5. T.K. Corwin, T.W. Devitt, M.A. Taft, A.C. Worrell III, International Technology for Non-Ferrous Smelting Industry, Noyes Data Corp., 1982

6. Annual Survey of Manufacturers, 1978-82

7. 10K report, St. Joe Lead Company (Now a subsidiary of Fluor)

APPENDIX C

DYNAMICS OF THE MRP PROGRAM IN INDIVIDUAL INDUSTRIES

TABLE C-1
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

PRIMARY SMELTERS*

REMOVALS BEGUN 1979-1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
60-69		1 (50%)		1 (50%)			2
70-79 (10%)	2 (2%)	13 (11%)	48 (39%)	43 (35%)	13 (11%)	4 (3%)	123
80-89	1 (1%)	18 (18%)	32 (32%)	35 (35%)	11 (11%)	4 (4%)	101
90-109		5 (12%)	22 (52%)	11 (26%)	3 (7%)	1 (2%)	42
110			3 (100%)				3
TOTAL:	3 (1%)	37 (14%)	105 (39%)	90 (33%)	27 (10%)	9 (3%)	271

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
40			1 (25%)	3 (75%)			4
40-49		9 (9%)	51 (49%)	34 (33%)	10 (10%)		104
50-60	3 (2%)	26 (19%)	53 (38%)	46 (33%)	9 (7%)	1 (1%)	138
Still on MRP		1 (4%)		7 (29%)	8 (33%)	8 (33%)	24
Terminated**		1 (100%)					1
TOTAL:	3 (1%)	37 (14%)	105 (39%)	90 (33%)	27 (10%)	9 (3%)	271

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes MRP data from primary smelter plants: 1008912, 1100272, 1199994, 1129272, 1040372.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-2
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

PRIMARY SMELTERS*

REMOVALS BEGUN 1979-1980

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
60-69		1 (100%)					1
70-79 (10%)	2 (2%)	11 (13%)	32 (39%)	28 (34%)	6 (7%)	4 (5%)	83
80-89	1 (1%)	18 (20%)	31 (34%)	28 (31%)	9 (10%)	4 (4%)	91
90-109		5 (12%)	21 (51%)	11 (27%)	3 (7%)	1 (2%)	41
110			3 (100%)				3
TOTAL:	3 (1%)	35 (16%)	87 (40%)	67 (31%)	18 (8%)	9 (4%)	219

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
40			1 (25%)	3 (75%)			4
40-49		7 (9%)	35 (47%)	23 (31%)	9 (12%)		74
50-60	3 (2%)	26 (20%)	51 (39%)	41 (31%)	9 (7%)	1 (1%)	131
Still on MRP		1 (11%)				8 (89%)	9
Terminated**		1 (100%)					1
TOTAL:	3 (1%)	35 (16%)	87 (40%)	67 (31%)	18 (8%)	9 (4%)	219

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes MRP data from primary smelter plants: 1008912, 1100272, 1199994, 1129272, 1040372.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-3
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL[a]

PRIMARY SMELTERS*

REMOVALS BEGUN 1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTAL
60-69				1 (100%)			1
70-79 (10%)		2 (5%)	16 (40%)	15 (38%)	7 (18%)		40
80-89			1 (10%)	7 (70%)	2 (20%)		10
90-109			1 (100%)				1
110							0
TOTAL:		2 (4%)	18 (35%)	23 (44%)	9 (17%)		52

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTAL
40							0
40-49		2 (7%)	16 (53%)	11 (37%)	1 (3%)		30
50-60			2 (29%)	5 (71%)			7
Still on MRP				7 (47%)	8 (53%)		15
Terminated**							0
TOTAL:		2 (4%)	18 (35%)	23 (44%)	9 (17%)		52

(a) Source: Charles River Associates questionnair , Spring 1982

*Includes MRP date from 5 primary smelter plants: 1008912, 1100272, 1199994, 1129272, 1040372.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-4
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL[a]

SECONDARY LEAD SMELTERS*
REMOVALS BEGUN 1979-1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
60-69				1 (17%)	2 (33%)	3 (50%)	6
70-79		4 (14%)	9 (31%)	5 (17%)	4 (14%)	7 (24%)	29
80-89		2 (12%)	3 (18%)	4 (24%)	2 (12%)	6 (35%)	17
90-109		1 (5%)	3 (15%)	3 (15%)	3 (15%)	10 (50%)	20
110		1 (11%)	2 (22%)		3 (33%)	3 (33%)	9
TOTAL:		8 (10%)	17 (21%)	13 (16%)	14 (17%)	29 (36%)	81

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
40			4 (67%)	1 (17%)	1 (17%)		6
40-49		4 (20%)	6 (30%)	4 (20%)	2 (10%)	4 (20%)	20
50-60		4 (17%)	7 (29%)	5 (21%)	7 (29%)	1 (4%)	24
Still on MRP				1 (5%)	4 (19%)	16 (76%)	21
Terminated**				2 (20%)		8 (80%)	10
TOTAL:		8 (10%)	17 (21%)	13 (16%)	14 (17%)	29 (36%)	81

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes 6 secondary smelters: 1086114, 1064018, 1036606, 1132166, 1008052, 1105012.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-5
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

SECONDARY LEAD SMELTERS*
REMOVALS BEGUN 1979-1980

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
60-69						3 (100%)	3
70-79		1 (7%)	5 (36%)	0	2 (14%)	6 (43%)	14
80-89		2 (17%)	1 (8%)	2 (17%)	1 (8%)	6 (50%)	12
90-109			3 (17%)	2 (11%)	3 (17%)	10 (56%)	18
110			1 (17%)		2 (33%)	3 (50%)	6
TOTAL:	0	3 (6%)	10 (19%)	4 (8%)	87 (15%)	28 (53%)	53

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS) 30	30-59	60-119	120-239	240-479	480	TOTALS
40			1 (100%)				1
40-49		1 (10%)	3 (30%)	1 (10%)	1 (10%)	4 (40%)	10
50-60		2 (11%)	6 (32%)	3 (16%)	7 (37%)	1 (5%)	19
Still on MRP						16 (100%)	16
Terminated**						7 (100%)	7
TOTAL:		3 (16%)	10 (19%)	4 (8%)	8 (15%)	28 (53%)	53

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes 6 secondary smelters: 1086114, 1064018, 1036606, 1132166, 1008052, 1105012.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-6
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

SECONDARY LEAD SMELTERS*
REMOVALS BEGUN 1981

DURATION OF REMOVAL (DAYS)

Removal Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
60-69				1 (33%)	2 (67%)		3
70-79		3 (20%)	4 (27%)	5 (33%)	2 (13%)	1 (7%)	15
80-89			2 (40%)	2 (40%)	1 (20%)		5
90-109		1 (50%)		1 (50%)			2
110		1 (33%)	1 (33%)		1 (33%)		3
TOTAL:		5 (18%)	7 (25%)	9 (32%)	6 (21%)	1 (4%)	28

RETURNS FROM MRP

DURATION OF REMOVAL (DAYS)

Return Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
40			3 (60%)	1 (20%)	1 (20%)		5
40-49		3 (30%)	3 (30%)	3 (30%)	1 (10%)		10
50-60		2 (40%)	1 (20%)	2 (40%)			5
Still on MRP				1 (20%)	4 (80%)		5
Terminated**				2 (67%)		1 (33%)	3
TOTAL:		5 (18%)	7 (25%)	9 (32%)	6 (21%)	1 (4%)	28

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes 6 secondary smelters: 1086114, 1064018, 1036606, 1132166, 1008052, 1105012.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-7
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

REMELTERS/RECYCLERS*

REMOVALS BEGUN 1979-1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
60-69		3 (7%)	15 (34%)	13 (30%)	11 (25%)	2 (5%)	44
70-79	1 (10%)		1 (10%)	4 (40%)	4 (40%)		10
80-89					1 (100%)		1
90-109						1 (100%)	1
110							0
TOTAL:	1 (2%)	3 (5%)	16 (29%)	17 (30%)	16 (29%)	3 (5%)	56

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
40	1 (2%)	1 (2%)	16 (36%)	13 (29%)	13 (29%)	1 (2%)	45
40-49		1 (100%)					1
50-60							
Still on MRP		1 (17%)		3 (50%)	2 (33%)		6
Terminated**				1 (25%)	1 (25%)	2 (50%)	4
TOTAL:	1	3	16	17	16	3	56

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes MRP data from 2 remelters/recyclers: 1098728, 1070184.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-6
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

REMELTERS/RECYCLERS*

REMOVALS BEGUN 1979-1980

DURATION OF REMOVAL (DAYS)

Removal Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
60-69		1 (7%)	1 (7%)	6 (40%)	5 (33%)	2 (13%)	15
70-79	1 (50%)				1 (50%)		2
80-89					1 (100%)		1
90-109						1 (100%)	1
110							0
TOTAL:	1 (5%)	1 (5%)	1 (5%)	6 (32%)	7 (37%)	3 (16%)	19

RETURNS FROM MRP

DURATION OF REMOVAL (DAYS)

Return Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
40	1 (5%)		1 (5%)	6 (32%)	7 (37%)	1 (5%)	16
40-49		1 (100%)					1
50-60							0
Still on MRP							0
Terminated**						2 (100%)	2
TOTAL:	1 (5%)	1 (5%)	1 (5%)	6 (32%)	7 (37%)	3 (5%)	19

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes MRP data from 2 remelters/recyclers: 1098728, 1070184.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-9
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL(a)

REMELTERS/RECYCLERS*

REMOVALS BEGUN 1981

DURATION OF REMOVAL (DAYS)

Removal Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
60-69		2 (7%)	14 (48%)	7 (24%)	6 (21%)		29
70-79			1 (13%)	4 (50%)	3 (38%)		8
80-89							0
90-109							0
110							0
TOTAL:		2 (5%)	15 (41%)	11 (30%)	9 (24%)		37

RETURNS FROM MRP

DURATION OF REMOVAL (DAYS)

Return Level (ug. Pb/ 100 ml. blood)	30	30-59	60-119	120-239	240-479	480	TOTALS
40		1 (3%)	15 (52%)	7 (24%)	6 (21%)		29
40-49							0
50-60							0
Still on MRP		1 (17%)		3 (50%)	2 (33%)		6
Terminated**				1 (50%)	1 (50%)		2
TOTAL:		2 (5%)	15 (41%)	11 (30%)	9 (24%)		37

(a) Source: Charles River Associates questionnaire, Spring 1982.

*Includes MRP data from 2 remelters/recyclers: 1098728, 1070184.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-10
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL

BATTERY INDUSTRY (INCLUDES INDUSTRIAL AND SLI BATTERY PLANTS)*
REMOVALS BEGUN 1979-1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
60			1 (50%)			1 (50%)	2
60-69			1 (5%)	14 (74%)	4 (21%)		19
70-79	4 (8%)	8 (16%)	10 (20%)	16 (31%)	3 (6%)	10 (20%)	51
80-89		1 (6%)	5 (29%)	3 (18%)	3 (18%)	5 (29%)	17
90-109			2 (67%)			1 (33%)	3
110						1 (100%)	1
TOTAL:	4 (4%)	9 (10%)	19 (20%)	33 (35%)	10 (11%)	18 (18%)	93

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
40			3 (21%)	6 (43%)	3 (21%)	2 (14%)	14
40-49	1 (2%)	5 (10%)	10 (20%)	12 (24%)	2 (4%)	5 (10%)	49
50-60		4 (25%)	3 (19%)	6 (38%)		3 (19%)	16
Still on MRP			1 (7%)	7 (47%)	4 (27%)	3 (20%)	15
Terminated**	3 (23%)		2 (15%)	2 (15%)	1 (8%)	5 (39%)	13
TOTAL:	4 (4%)	9 (10%)	19 (20%)	33 (35%)	10 (11%)	18 (18%)	93

*Includes MRP data from 12 battery plants: 1086514, 1021468, 1012010, 2189438, 1184234, 1043162, 1168132, 2121084, 1021812, 1181646, 1119614, 1004868.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

TABLE C-11
MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVFL

BATTERY INDUSTRY (INCLUDES INDUSTRIAL AND SLI BATTERY PLANTS)*
REMOVALS BEGUN 1979-1980

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
60						1 (100%)	1
60-69							0
70-79	4 (9%)	8 (17%)	10 (21%)	12 (26%)	3 (6%)	10 (21%)	47
80-89		1 (6%)	5 (31%)	3 (19%)	2 (13%)	5 (31%)	16
90-109			1 (50%)			1 (50%)	2
110						1 (100%)	1
TOTAL:	4 (6%)	9 (13%)	16 (24%)	15 (22%)	5 (8%)	18 (27%)	67

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
40			2 (25%)	1 (13%)	3 (38%)	2 (25%)	8
40-49	1 (3%)	5 (17%)	9 (30%)	9 (30%)	1 (3%)	5 (17%)	30
50-60		4 (29%)	3 (21%)	4 (29%)		3 (21%)	14
Still on MRP						3 (100%)	3
Terminated**	3 (25%)		2 (17%)	1 (8%)	1 (8%0	5 (42%)	12
TOTAL:	4 (67%)	9 (13%)	16 (24%)	15 (22%)	5 (8%)	18 (27%)	67

*Includes MRP data from 12 battery plants: 1086514, 1021468, 1012010, 2189438, 1184234, 1043162, 1168132, 2121084, 1021812, 1181646, 1119614, 1004858.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

MEDICAL REMOVAL DURATION BY INDUSTRY AND REMOVAL LEVEL

BATTERY INDUSTRY (INCLUDES INDUSTRIAL AND SLI BATTERY PLANTS)*

REMOVALS BEGUN 1981

Removal Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
60			1 (100%)				1
60-69			1 (5%)	14 (74%)	4 (21%)		19
70-79				4 (100%)			4
80-89					1 (100%)		1
90-109			1 (100%)				1
110							0
TOTAL:			3 (12%)	18 (69%)	5 (19%)		26

RETURNS FROM MRP

Return Level (ug. Pb/ 100 ml. blood)	DURATION OF REMOVAL (DAYS)						
	30	30-59	60-119	120-239	240-479	480	TOTALS
40			1 (17%)	5 (83%)			6
40-49			1 (20%)	3 (60%)	1 (20%)		5
50-60				2 (100%)			2
Still on MRP			1 (8%)	7 (60%)	4 (33%)		12
Terminated**				1 (100%)			1
TOTAL:			3 (12%)	18 (69%)	5 (19%)		26

*Includes MRP data from 12 battery plants: 1086514, 1021468, 1012010, 2189438, 1184234, 1043162, 1168132, 2121084, 1021812, 1181646, 1119614, 1004068.

**"terminated" includes employees who permanently left employment because they were fired, quit, retired, went on permanent medical leave, etc.

CASE STUDY

TECHNOLOGIES FOR CONTROLLING WORKER EXPOSURE TO

SILICA STUDY

by

John L. S. Hickey, Ph.D.
Carol H. Rice, Ph.D.
Brian A. Boehlecke, M.D.

University of North Carolina
Occupational Health Studies Group
Chapel Hill, NC 27514

A Report Performed for and Submitted to the

CONGRESS OF THE UNITED STATES
Office of Technology Assessment

August 1983

CASE STUDY

TECHNOLOGIES FOR CONTROLLING WORKER EXPOSURE TO

SILICA STUDY

by

John L. S. Hickey, Ph.D.
Carol H. Rice, Ph.D.
Brian A. Boehlecke, M.D.

University of North Carolina
Occupational Health Studies Group
Chapel Hill, NC 27514

A Report Performed for and Submitted to the

CONGRESS OF THE UNITED STATES
Office of Technology Assessment

August 1983

ACKNOWLEDGEMENTS

The authors wish to thank Ms. Pamela Hooker of the UNC Occupational Health Studies Group for format preparation and typing of this report.

TABLE OF CONTENTS

PAGE

LIST OF TABLES iii

CHAPTER 1: EXECUTIVE SUMMARY 1

- Silicosis 1
- Silica Exposure 2
- Control of Exposure 3
- Regulation of Exposure 4
- Obstacles to Silica Dust Control 4
- Strategies for Silicosis Prevention 6

CHAPTER 2: OCCURRENCE OF SILICOSIS 8

CHAPTER 3: SILICA PRODUCTION AND USE IN THE UNITED STATES 15

- Production 15
- Industrial Sand 15
- Construction Sand 16
- Outlook for Sand Use 16

CHAPTER 4: WORKERS POTENTIALLY EXPOSED TO SILICA 19

- Exposed Population by Industry 19
- Exposed Population by Process 21
  - Foundries 23
  - Abrasive Blasting 24
  - Silica Flour 25

CHAPTER 5: WORKER EXPOSURE TO AIRBORNE SILICA DUST . . . 28

- Background 28
- Sources of Silica Dust 28
- Worker Exposure Levels 30

CHAPTER 6: CONTROL OF EXPOSURE TO AIRBORNE SILICA DUST 36

- Introduction 36
- Mode of Exposure 36
- Concepts of Control 38
  - Substitution 38
  - Process Change 38
  - Isolation 39

PAGE

Ventilation 40
Personal Protection 41
Administrative Controls 42
Regulatory Compliance Strategy 43
Evaluation of Silica Dust Controls 45
Substitution 45
Process Change 46
Isolation 47
Ventilation 48
Respiratory Protection 48
Summary 49

CHAPTER 7: REGULATORY CONTROL AND MEASUREMENT OF SILICA DUST EXPOSURE 51

Regulatory Control 51
Measurement of Exposure 54

CHAPTER 8: OBSTACLES TO CONTROLLING SILICA EXPOSURE . . . 59

Introduction 59
Policy Issues 59
Reliance on After-the-Fact Controls 60
Difficulty in Measuring Exposure 60
Inconsistencies in Silica Standards 60
Variety of Exposure Conditions 63
Unawareness of Hazard 63

CHAPTER 9: STRATEGIES FOR SILICOSIS PREVENTION 65

Introduction 65
Exposure Prevention Technology 65
Determination of Health Effects Thresholds 66
Determination of Silica Exposure 66
Unification of Exposure Limits 67
Early Health Effects Detection 67
Respirator Effectiveness and Acceptability 67

CHAPTER 10: REFERENCES AND GLOSSARY 69

References 69
Glossary 82

LIST OF TABLES

PAGE

Table 2-1: Number of Workers Exposed to Silica Dust and Estimated Number of Silicosis Cases 14

Table 3-1: Industrial Sand Sold or Used by U.S. Producers, by Major Use, 1980 17

Table 4-1: Production Workers in Industries with Potential Exposure to Free Silica 20

Table 4-2: Employees Exposed Full-time to Silicon Dioxide With and Without Controls 22

Table 4-3: U.S. Abrasive Blasters and Silica Sand Use, by Industry 26

Table 5-1: Silica Exposure in Foundries 34

Table 6-1: Concepts of Control of Silica Exposure 37

Table 7-1: U.S. Exposure Limits for Silica-Containing Dust 52

Table 8-1: Derived Silica Exposure Limits 62

CHAPTER 1

EXECUTIVE SUMMARY

Silicosis

Silicosis is a potentially disabling lung disease resulting from the inhalation, deposition and retention in the lungs of fine dust particles containing crystalline (free) silica. Three forms of the disease are recognized: classical silicosis, acute silicosis and mixed dust fibrosis.

Development of classical (or chronic) silicosis usually requires 20 years or more of exposure to airborne silica-containing dust. Acute silicosis may occur within six months following exposure to extremely high silica dust concentrations. Mixed dust fibrosis is similar to classical silicosis, but pathological findings also reflect changes induced by materials accompanying silica in the dust.

Silicotic workers appear to suffer more episodes of chest illness than workers without silicosis, and the mortality rate for non-malignant respiratory disease is significantly higher in workers receiving compensation benefits for silicosis than in the general population. A complication of silicosis, progressive massive fibrosis, results in significant impairment in lung function and may result in respiratory failure and secondary heart disease. Tuberculosis and other pulmonary infections may complicate acute or chronic silicosis, and significantly shorten life expectancy. Whether workers exposed to silica have an increased risk of lung cancer has not yet been established.

Diagnostic procedures do not detect silicosis at a reversible stage, and no medical treatment is available to alter the course of silicosis. Therefore, prevention is the only effective means of control.

Despite the fact that silica exposure has been associated with silicosis for many decades, and technological means of controlling exposure to silica dust have been available for at least as long, silicosis continues to occur in the U.S. A minimum of 59,000 cases of silicosis may be expected on the basis of current exposure levels and numbers of exposed workers in U.S. industry, principally in mining, foundries, stone, clay and glass products manufacture, and abrasive blasting.

Silica Exposure

The opportunity for occupational exposure to silica is widespread in industry. Silica is a major component of the earth's crust; it is used in many industries and is an unwanted constituent of many ores and other raw materials. Over 402 million tons of silica-containing sand were produced in the U.S. in 1980. Of this total, nearly 300 million tons were used in glassmaking, foundry and abrasive material operations.

There are an estimated 1.3 million production workers in industries with potential exposure to free silica. The industries accounted for over $88 billion in "value of shipments" in 1977. An estimated 40 percent of these workers are in worksites with no silica dust controls. Historically, the severest exposure to silica have occurred in granite and stone working, foundries, mining, and abrasive blasting. The production and use of silica flour have recently been recognized as additional occupations with high potential for silicosis, because of the extremely fine size of the particles produced.

Control of Exposure

Methods for preventing silica exposure have long been known. These are Substitution, the substitution of a less hazardous material for silica; Process change, such as the substitution of a non-dusty for a dusty process; Isolation, the automation, enclosure or isolation by distance of a silica exposure source; Ventilation, the use of local exhaust ventilation at dust generating points or the use of general ventilation to dilute dust concentrations; Personal protection, the use of respirators for workers in dusty areas; and Administrative controls, which include worker training, maintenance of dust control devices, housekeeping, and other managerial exposure-prevention procedures.

All of these controls are in use to varying degrees for control of silica exposure. However, review of the literature and statistics on compliance with Federal silica exposure standards indicate that complete control of silica dust exposure has not been achieved to date.

Regulation of Exposure

Occupational exposure to silica is regulated by the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA), both in the U.S. Department of Labor. Current mandatory exposure limits have developed over the years from earlier voluntary U.S. exposure limits. The current industrial occupational exposure limit for respirable quartz (one form of free silica) is 100 micrograms/cubic meter of air ($\mu g/m^3$); the limit for respirable cristobalite and tridymite (two forms of free silica more toxic than quartz) is 50 $\mu g/m^3$. The National Institute for Occupational Safety and Health (NIOSH) has recommended an occupational exposure limit of 50 $\mu g/m^3$ for all forms of free silica. NIOSH also advocates a ban on the use of silica sand for abrasive blasting, because of the fine dust particles generated.

Obstacles to Silica Dust Control

Factors which may be obstacles to controlling worker exposure to silica dust are:

1. Cost to employers of inaugurating and maintaining controls.
2. Limited epidemiological data on which to base a safe exposure limit. Most current silicosis cases resulted from exposures during a period when "dust counts" were used to measure exposure. Whether adherence to current

limits, based on mass, offer the same degree of protection has not been confirmed, although evidence supports the NIOSH recommended limit.

3. The lack of economic incentives, as through increased workers' compensation insurance premiums and penalties for violations of standards, for firms to control exposure.
4. The magnitude of the task of monitoring compliance with exposure limits. For example, the Federal Occupational Safety and Health Administration (OSHA) annually inspects worksites employing only 2 percent of the U.S. workforce under its jurisdiction. State OSHA programs annually inspect worksites with an additional 4 to 6 percent of the workforce.
5. The reliance on after-the-fact controls. Control efforts generally aim at controlling silica dust after it becomes airborne; prevention of dust generation by new technology is of comparatively recent development and not yet in wide use.
6. Difficulty in measuring silica concentrations in respirable dust samples. The determination of silica is a relatively time-consuming process; thus widespread silica assay in workplaces is not practiced. OSHA, for example, does not do any assays for tridymite. The search for previously unreported sources of silica exposure in industry is

also limited by the possibility that analytical facilities may be overloaded.

7. The inconsistencies in silica exposure standards. Due to their history and the variety of standard-setting agencies and institutions, occupational standards for silica exposure paradoxically are not stated in terms of silica, but in terms of respirable dust. Further, when converted to a basis of silica, the various limits are different. This situation may result in poorer silica control.
8. The variety of exposure conditions make any single approach to control of silica exposure inappropriate. OSHA has been asked to consider at least three separate standards; for general industry, for abrasive blasting, and for abrasive blasting in construction.

Strategies for Silicosis Prevention

Several strategies are needed for prevention of silicosis through more effective control of silica exposure. Some promising policy and technological strategies are listed below; others should emerge with time.

1. Placement of emphasis on developing technology to prevent generation of silica dust, rather than only on refining measures to avoid exposure to dust after it is generated, should produce more effective exposure controls. Refinement of current techniques in some applications will remain necessary.

2. The determination of a level of silica exposure which will avoid development of new cases of silicosis, and establishment of an exposure limit or limits stated in terms of silica itself, should remove the uncertainty of the validity of current exposure limits and the confusion surrounding calculation of current regulatory limits.

3. Development of a simplified, accurate and rapid method to determine silica content of respirable air samples should enhance both control of silica exposure and research to determine the dose-response relationship for work-related airborne silica exposure.

4. Development of medical procedures for detecting silicosis at an early state could provide a means for early removal of workers from exposure, thus minimizing the effects of silica exposure already received.

5. Further improvement in respirator acceptability could encourage more conscientious use of respirators in situations where other exposure control measures are not feasible.

CHAPTER 2

OCCURRENCE OF SILICOSIS

The inhalation, deposition, and retention of fine dust containing crystalline silica is associated with three main forms of lung damage: classical nodular silicosis, acute silicosis, and mixed dust fibrosis (Seaton, 1975; Ziskind, 1976a; Parkes, 1982). All three result from injury and death of lung scavenger cells (macrophages) which ingest particles containing silica, thereby releasing chemical factors which result in inflammation, damage to other cells of the airspace walls, and fibrosis (deShazo, 1982).

The distinctive pathologic feature of classical silicosis is the silicotic nodule, a small rounded lesion with a core of concentrically arranged accellular connective tissue and some silica, a middle layer of cellular connective tissue, and a peripheral zone of macrophages and silica particles (Seaton, 1975; Ziskind 1976a; Parkes, 1982, Spencer, 1977). These nodules occur most prominently adjacent to the terminal airways (respiratory bronchioles), small vessels, and near the fibrous tissue in the lung substance (septae) or covering of the lungs (pleura). The airspace walls between these nodules may be relatively normal. As the disease progresses, more nodules form and in some persons the small nodules coalesce into larger masses of dense unstructured connective tissue which contracts and distorts the remainder of the lung. This complication is called progressive massive fibrosis (PMF) and is usually associated with a significant reduction in ventilatory capacity and impairment in the gas-exchanging function of the lungs.

In mixed dust fibrous, the inhaled dust contains substances (e.g., hematite or kaolin) which modify the tissue response to silica,and the focal lesions may assume a more irregular shape and lack the concentric arrangement typical of classical silicotic nodules. Although mixed dust fibrosis is generally similar to classical silicosis in its clinical features, due to the lower percentage of silica in the dust the damage is usually less severe than that seen with more intense exposure to silica, and progression to massive fibrosis is unusual.

Development of chronic silicotic nodules recognizable on chest radiograph as small rounded densities usually requires 20 or more years of exposure when the airborne dust in the workplace contains less than 30 percent free silica. However, with exposure to high dust concentrations or to dust with high silica content, the disease may follow an accelerated course, with lesions appearing on chest radiograph from 5 to 15 years from the onset of exposure. With extremely intense exposures, as may be encountered in closed spaces where silica-containing abrasives are used (e.g., sandblasting in ships' holds), an acute form of disease may occur within six months. This is characterized by an intense inflammatory response in the airspace walls and filling of the airspaces (alveoli) with macrophages and fluid rich in lipo-protein. Progression results in diffuse inflammation and fibrosis without development of well defined silicotic nodules.

Diagnosis of silicosis depends primarily on a history of exposure to dust containing free silica and the characteristic findings on chest radiograph. Nodular silicosis produces small rounded opacities on the radiograph, usually more prominent in the upper zones. Enlargement of lymph nodes near the origin of the large airways from the trachea may be seen, and occasionally a fine layer of calcium is deposited at the outer edge of these nodes. This pattern of "egg-shell" calcification is typical for silicosis, but not unique to this condition. When progressive massive fibrosis occurs, large dense masses are seen, usually in the upper zones, and overdistention of the remaining lung may be recognized by loss of normal lung markings on the radiograph. There are no other currently recognized clinical findings which are diagnostic for silicosis.

In chronic silicosis, pulmonary function testing usually shows little, if any, impairment of ventilatory function until the stage of progressive massive fibrosis is reached (Seaton, 1975; Ziskind, 1976a; Parkes, 1982; Jones, 1975). At this stage, both obstruction to airflow and reduction in total lung capacity with impairment of gas transfer may be present. A decrease in arterial blood oxygen content may be present at rest or may occur only during exercise. Shortness of breath on exertion is commonly present. Workers developing acute silicosis present a more toxic appearance with fever, weight loss, weakness, and shortness of breath. Pulmonary function testing shows impairment of gas transfer and the chest radiograph is characterized by a diffuse haze in the lower zones, sometimes with fine linear and small rounded opacities without the sharply defined nodules of classical silicosis.

The natural history of disease depends upon the rate of deposition, upon the total amount of silica retained in the lungs, and probably also upon certain immunologic characteristics of the host. Workers with simple nodular silicosis have little alteration in pulmonary function directly attributable to this condition, but do appear to suffer more episodes of non-specific chest illnesses than workers without silicosis (Irwig, 1978). The mortality rate for non-malignant respiratory disease has been found to be significantly elevated above that of the general population in workers receiving workers' compensation benefits for silicosis (Finkelstein, 1982). Progressive massive fibrosis is associated with respiratory failure and secondary heart disease, which significantly shorten life expectancy. A common complication of silicosis, especially in the accelerated and complicated forms, is tuberculosis or mycobacterial infections with atypical organisms (Baily, 1974). This may occur in up to 25 percent of those with rapidly developing silicosis and is associated with a significant shortening of life expectancy (Finkelstein, 1982).

Whether workers exposed to airborne silica are also subject to an increased risk of lung cancer has not yet been established (Goldsmith, 1982). Animal studies have generally not shown pure silica to be an inducer of lung cancer, but it may promote the carcinogenesis of other airborne materials in the workplace (such as polyaromatic hydrocarbons) (Stenback, 1979). Two recent studies of workers with silicosis have shown increased lung cancer mortality over that expected in the general population, but information on other contributing factors, such as cigarette smoking, was not available (Finkelstein, 1982; Westerholm, 1980). In one of these studies (Finkelstein, 1982), the relative risk for lung cancer was not elevated in workers diagnosed as silicotic from 9 to 17 years before date of the follow-up. Whether this experience will continue with longer observation remains to be seen. At present, the relationship between lung cancer and silica exposure remains unconfirmed.

Because no medical treatment is available to alter the course of silicosis, prevention is the only effective means of control. The National Institute for Occupational Safety and Health (NIOSH) has estimated that over one million workers are employed in industries with potential exposure to silica (NIOSH, 1974). Despite good evidence that dust control can effectively reduce the incidence of silicosis (Ashe, 1964), workers are still being exposed to airborne levels of free silica which are known to be associated with disease. In the silica flour industry, 53 percent of workplace air samples collected from 1974 to 1979 were above the currently accepted permissible exposure limit (Banks, 1981), and a survey of two facilities discovered 20 percent of current workers and 55 percent of former workers (with one or more years of exposure) to have silicosis (Banks, 1981a). Seven workers had progressive massive fibrosis, including four who developed this complication with less than six years of exposure.

Table 2-1 (reprinted from reference USDOL, 1980) shows that a minimum of 59,000 cases of silicosis may be expected based on current exposure levels and numbers of exposed workers. These figures do not include a large number of agricultural, chemical and construction workers exposed to silica for whom neither exposure data nor epidemiologic studies exist, and this estimate is considered to be the lower bound of potential cases of silicosis (USDOL, 1980).

In North Carolina a surveillance program of the "dusty trades" (granite sheds, quarries, mines, etc.) in operation since 1935 has continued to uncover new cases of silicosis on chest radiograph each year since its inception, including 11 new cases in 1982 (out of approximately 7,000 workers examined) (Morris, 1983).

Thus, this entirely preventable, but untreatable, condition continues to be a public health problem.

Table 2-1: Number of Workers Exposed to Silica Dust and Estimated Number of Silicosis Cases

Industry	Current Number of Exposed Workers	Estimated Number of Silicosis Cases
Mining		
Metal	24,000	816
Coal	126,000	630
Nonmetal	7,000	56
Quarry		
Granite	4,000	400
Sand/Gravel	40,000	4,000
Stone, Clay and Glass Products	511,000	31,500
Foundries		
Iron and Steel	192,000	16,700
Nonferrous	75,000	
Abrasive Blasting		5,000
TOTAL	1,057,000	59,102

SOURCE: USDOL, 1980: U.S. Department of Labor, Office of the Assistant Secretary for Policy, Evaluation and Research, *An Interim Report to Congress on Occupational Diseases*, Washington, DC, 1980.

CHAPTER 3

SILICA PRODUCTION AND USE IN THE UNITED STATES

Production

A total of over 402 million tons of sand, with a value of over $1.2 billion was produced in the United States in 1980, the latest year for which complete figures are available (Tepordei, 1982). The two types of sand produced are construction sand and industrial sand.

Industrial Sand

Industrial sand is the material of primary concern in occupational silica exposures. Industrial sand production accounted for 7 percent (28.7 million tons) of all sand produced in 1980, and 23.6 percent of the total value ($287 million), with a value of from $7 to $27 per ton. About 45 percent of 1980 industrial sand production was consumed as glassmaking sand, 31 percent as foundry sand, and 7 percent as abrasive sand.

The five leading States in industrial sand production in both 1980 and 1981 were Illinois, Michigan, New Jersey, Texas and California. Their combined production represented 52 percent of the national total. Ten companies operating 46 facilities, produced 61 percent of the total. These percentage figures also include industrial gravel, which amounts to less than 3 percent of industrial sand production. Approximately 4 percent of industrial sand produced is exported, primarily to Canada and Mexico. Imports are nil (Tubich, 1981).

Table 3-1 indicates the use, by industrial process, of industrial sand in 1980, giving tonnage used by region and tonnage and value for the U.S. as a whole.

Construction Sand

Construction sand, as its name implies, is used in all types of construction. Construction sand accounted for 93 percent (373.4 million tons) of 1980 U.S. sand production, with a value of $925 million, or $2.50 per ton. The five leading States in construction sand and gravel production in 1980 were California, Alaska, Texas, Ohio and Michigan, which accounted for 35 percent of total production. Almost no construction sand or gravel (<0.2 percent) is exported or imported (Tepordei, 1982).

Outlook for Sand Use

Construction sand use in 1980 was down 24 percent from 1978, while average value rose from $2.02/ton in 1978 to $2.48/ton in 1980. By contrast, use of industrial sand dropped 10 percent from 1978 to 1980, while average value rose from $7.65/ton in 1978 to $9.98/ton in 1980. Use in 1981 rose 2 percent to 29.2 million tons, with an average value of $11.16/ton.

Four major industrial sand producers are expanding their facilities because of increased demand. A facility in California is doubling its capacity to 800,000 tons/yr; one in Nevada is tripling its production to 1 million tons/yr; and two companies are opening new facilities in Minnesota (Tepordei, 1982).

Table 3-1: Industrial Sand Sold or Used by U.S. Producers, by Major Use, 1980

Major Use	Quantity, thousands of short tons (rounded) Northeast	North Central	South	West	All U.S.	Total Value (1,000s)	Value per Ton
Glassmaking	2,530	3,725	4,575	2,072	12,905	$119,617	$9.27
Foundry	769	6,808	1,242	219	9,036*	71,042	7.86
Metallurgical	1	154	2	140	297	2,698	9.08
Abrasives**	162	309	1,307	151	1,928*	25,720	13.34
Chemicals	73	211	132	40	456	4,739	10.39
Fillers, pulverized**	39	82	97	7	225	6,977	31.01
Ceramics, pulverized**	11	88	46	4	148	4,136	27.95
Filtration	71	63	89	11	234	2,788	11.91
Traction (engine)	17	188	140	58	403	2,958	7.34
Coal washing	2	10	31	-	43	404	9.40
Roofing	17	22	112	52	203	2,623	12.92
Hydraulic fracture	1	379	688	109	1,177	24,023	20.41
Other	333	648	371	328	1,679	18,958	11.29
TOTAL	4,027	12,680	8,833	3,191	28,730	$285,700	$9.98

* Includes 316,000 tons of pulverized sand. ** Includes silica flour.

SOURCE: V. V. Tepordei, "Sand and Gravel," in Minerals Yearbook, 1981, Vol. II, Table 6, U. S. Department of the Interior, Bureau of Mines, 1982.

The foundry industry, which uses from 9 to 10 million tons of silica sand per year could conceivably affect industrial sand production by use of an alternative material for making molds, blast cleaning and other uses. However, total production of non-silica aggregates suitable as alternates is barely 1/2 million tons/yr, and their cost is 4 to 6 times that of silica sand (Tubich, 1981).

An estimated 13.6 million tons of sand are used in non-foundry abrasive blasting operations (Hickey, 1978), of which 1.6 million tons/yr are industrial sand (Tepordei, 1982). This indicates that much construction sand is used for abrasive blasting. Banning the use of silica sand for sandblasting as proposed by NIOSH (1974) and considered by OSHA (Hickey, 1978) would likely have a small negative effect on industrial and construction sand production.

CHAPTER 4

WORKERS POTENTIALLY EXPOSED TO SILICA

Exposed Population by Industry

In ancient times, silica exposure and silicosis were associated primarily with quarrying and mining. With the growth of technology and industry, the use and processing of silica-containing materials, and resultant exposure to silica dust, now occurs in many industries (NIOSH, 1980). The objective of this chapter is to define the overall U.S. worker population exposed to silica, by industry, and to discuss specific processes and occupations in which such exposure occurs.

Several estimates have been made of the number of U.S. workers exposed to free silica dust, mainly quartz. Table 4-1 summarizes the number of production workers in industries traditionally associated with silica exposure, in the same format used by others (NIOSH, 1974; USDOL, 1980). Allowing for differences in dates of estimates, the figures are in substantial agreement; that is, approximately one million workers.

Table 4-1 includes three additional industry groups considered to have potential silica dust exposure: fabricated structural metals; plating, polishing, and sandblasting; and shipbuilding and repair (Hickey, 1978). Addition of these groups adds 263,900 to the exposed population. Not all of the listed production workers are exposed to

Table 4-1: Production Workers in Industries with Potential Exposure to Free Silica

SIC Code	Industry Description	No. of Production Workers	Value of Shipments (10^6 $)
10	Metal mining	64,700	5,369.3
11,12	Coal mining	209,500	16,935.7
14	Non-metallic minerals, except fuels	95,100	6,999.9
32	Stone, clay, and glass products	423,500	31,149.5
332	Iron and steel foundries	183,700	10,830.3
336	Non-ferrous foundries	68,600	3,826.1
	TOTAL	1,045,100	$75,110.8
ADDITIONAL OCCUPATIONS WITH SILICA EXPOSURE			
3441	Fabricated structural metal	72,800	5,505.2
3471	Plating, polishing, sandblasting	51,200	1,848.5
3731	Shipbuilding and repair	139,900	6,495.1
		263,900	$13,848.8

Sources: U.S. Department of Commerce, Bureau of the Census, 1977 Census of Manufactures, Vol. II, and 1977 Census of Mineral Industries, 1981.

free silica. The proportion varies from most of the metal miners to perhaps 20 percent of the stone, clay, and glass product workers. The figures omit substantial numbers of the 2.5 million persons employed in agriculture, 0.6 million in production of chemicals and allied products, and 0.6 million in heavy construction, including tunnel construction, many of whom are exposed to free silica (NIOSH, 1974). One measure of the importance of the industries where silica exposure occurs can be seen in the last column of Table 4-1, which shows a total value of shipments by these industries of over $88 billion annually.

The National Occupational Hazard Survey (NIOSH, 1978) provides a detailed estimate of occupational exposure to free silica. In 1972-1974 NIOSH conducted walk-through surveys of 5,000 randomly selected workplaces covering 66 2-digit Standard Industrial Classifications (SICs) for potential exposure to chemical and other hazards. No samples were collected. Table 4-2 was compiled from the published report, and shows the projected number of U.S. workers exposed full-time (over 4 hours/day) to free silica to be 259,039. An additional 2,950,000 persons in these industries are reported to be exposed less than 4 hours/day. Data from a similar 1980 study are not yet available.

Exposed Population by Process

Three industrial activities have been identified as having particularly serious exposure hazards to free silica. These are the foundry industry, abrasive blasting, and manufacture and use

Table 4-2: Employees Exposed Full-time[a] to Silicon Dioxide[b] With and Without Controls

Industry SIC and Description	No. of Plants	No. of Employees Exposed		
		All	No Controls	% With No Controls
All Industries	238,088	259,039	137,833	60.9
Agri. Svcs., Forestry, Fisheries	916	1,246	364	29.2
Mining (Oil and Gas)	309	0	0	-
Contract Construction	30,881	11,989	3,773	31.5
Manufacturing (SICs 19-39)	77,101	223,369	134,572	60.2
19 Ordnance and Accessories	92	615	44	7.2
20 Food and Kindred Products	7,300	0	0	-
21 Tobacco Manufactures	90	0	0	-
22 Textile Mill Products	737	225	225	100.0
23 Apparel & Other Textile Products	2,433	0	0	-
24 Lumber and Wood Products	1,333	1,811	1,581	87.3
25 Furniture and Fixtures	1,741	2,763	1,562	56.5
26 Paper and Allied Products	2,705	205	75	36.6
27 Printing and Publishing	5,431	802	802	100.0
28 Chemicals and Allied Products	4,357	2,122	442	20.8
29 Petroleum and Coal Products	709	1,618	677	41.8
30 Rubber & Plastics Products, NEC	2,715	1,637	839	51.3
31 Leather and Leather Products	543	674	672	99.7
32 Stone, Clay, and Glass Products	5,991	39,961	37,441	93.7
33 Primary Metal Industries	3,821	35,319	31,316	88.7
34 Fabricated Metal Products	15,384	50,702	18,974	37.4
35 Machinery, Except Electrical	10,685	41,043	15,555	37.9
36 Electrical Equipment & Supplies	3,405	2,033	1,709	84.1
37 Transportation Equipment	3,005	36,553	20,302	55.5
38 Instruments & Related Products	1,633	996	927	93.1
39 Miscellaneous Manufacturing Industries	2,991	4,290	1,431	33.4
Transportation and Other Public Utilities	12,221	265	219	82.6
Wholesale and Retail Trade	65,736	2,359	556	23.6
Finance, Insurance & Real Estate	5,478	0	0	-
Services	45,445	19,811	18,349	92.6

[a] Exposed more than 4 hrs/day; an additional 2,950,000 are exposed part-time in these industries.

[b] Report considers silicon dioxide to be free silica.

SOURCE: U.S. Dept. of Health Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, National Occupational Hazard Survey--Volume III Survey Analysis and Supplemental Tables, HEW Publication No. (NIOSH) 78-114, 1978.

of silica flour (Oudiz, 1983; Hickey, 1978; Banks, 1981). Therefore these activities are discussed in some detail below. Although silica exposures are also known to occur in mining, this report has focused on industrial exposures.

Foundries

The foundry industry uses 10 million tons of silica sand annually. Sand is used to make molds into which molten metal is poured to form castings of various shapes. After castings solidify, the molds are broken and the castings removed (shakeout), and the sand is milled to granular size for reuse in new molds. Some sand adheres to hardened castings; this is removed, usually by abrasive blasting. Surfaces of castings are also smoothed by abrasive wheel grinding. All of these processes generate airborne dust containing silica. Areas in foundries where silica sand is used and the estimated number of production workers in each are listed below (Tubich, 1981).

Foundry Process	No. of Employees
Cleaning and Finishing	70,400
Sand Systems	4,600
Shakeout and Core Knockout	10,900
Material Handling	24,700
Melting and Pouring	29,800
Molding and Coremaking	116,800
TOTAL	257,200

Exposure to silica dust in foundries is made particularly hazardous because cristobalite and tridymite (also forms of crystalline free silica), as well as quartz, may appear in foundry dust. Both of these crystalline structures result from transformation of quartz caused by exposure to the high temperatures encountered in foundries (NIOSH, 1978a). Cristobalite and tridymite are considered to present greater exposure hazards than quartz, because of higher toxicity (ACGIH, 1982b).

Abrasive Blasting

Abrasive blasting is a process in which a stream of high velocity particles is directed through a nozzle or channel against a surface in order to finish or clean it, or to relieve internal stress. The high velocity is achieved with centrifugal force or air pressure (Hickey, 1978). Abrasive blasting is used to clean sand from foundry castings, to prepare ship hulls and metal bridges for painting, to clean the surfaces of stone buildings, and for many similar purposes. Many abrasive blasting processes generate airborne dust containing silica.

Abrasive blasting with silica sand presents a particular hazard for several reasons (Hickey, 1978). First, much of the sand used is fractured into particles of respirable size. Second, the sand is often reused for blasting, thus generating even finer dust particles and compounding the airborne silica problem. Third, much blasting is done in the open (on ship hulls, buildings, large castings, etc.) where dust control is not feasible. It is estimated that there are nearly 80,000 abrasive blasters in the United States. These are classified by industry and silica sand use in Table 4-3. The sand blasters listed for foundries are also included in the foundry population exposed to silica dust.

Silica flour

Silica flour is produced by mining, crushing and grinding quartz sand to a very fine particle size, followed by packaging for shipment. All of these processes generate airborne dust containing silica. The flour is used in the manufacture of abrasive cleaners (such as metal polish, toothpaste and abrasive soaps), and as a component of paint, molds, concrete blocks and road surfacing mixtures (NIOSH, 1981). Airborne silica-containing dust may also be generated during unpackaging of the flour and in further processing into end-products.

The population exposed to silica flour has not been as well defined as those of foundry workers and abrasive blasters. However, there are at least 27 U.S. producers of silica flour employing at least 1,350 workers (Banks, 1981). Extent of silica flour use may be approximated from Table 3-1, which shows that 689,000 tons of pulverized (ground) industrial sand were used in 1980 in foundries,

Table 4-3: U.S. Abrasive Blasters and Silica Sand Use, by Industry

SIC	Industry Description	No. of Abrasive Blasters	Silica Sand Used 10^6 tons/yr)
1621	Heavy Construction	10,666	5.8
1721	Cleaning and Painting of Buildings, Ships Bridges	31,970	5.9
33--	Foundries, all types	11,156	1.1
----	Other SICs	24,073	2.9
	TOTALS	77,865	15.7

SOURCE: J. L. S. Hickey, et al., Research Triangle Institute, Abrasive Blasting, Technological Feasibility Assessment and Economic Impact Analyses of the Proposed Federal Standard, contract no. J-9-F-6-0225, submitted to the Occupational Safety and Health Administration, U. S. Department of Labor, Washington, D.C., September 1978.

for scouring cleaners, as fillers in rubber and paint, and in the ceramics industry.

CHAPTER 5

WORKER EXPOSURE TO AIRBORNE SILICA DUST

Background

This chapter summarizes the levels of exposure to airborne silica found in U.S. industries, summarized primarily from three sources. The first is the original "Criteria for a Recommended Standard" (NIOSH, 1974) which reviewed the literature on silica exposure levels through 1974. The second source is "Update of the Literature: Crystalline Silica" (NIOSH, 1980). The third source is literature published since 1980 up through presentations at the American Industrial Hygiene Conference in May 1983. Emphasis is on recent American (U.S. and Canadian) exposure levels, as being indicative of current exposures. As a basis of judging whether exposures are "high" or "low," the reader may wish to use the finding that no silicosis cases have been found to result from exposure to 2-4 millions of dust particles per cubic foot of air (mppcf) or to the recommended exposure limit of 50 micrograms of dust per cubic meter of air ($\mu g/m^3$) (NIOSH, 1974).

Sources of Silica Dust

Silica (silicon dioxide) is found virtually everywhere since it constitutes 60 percent of the earth's crust. The opportunity for exposure to airborne crystalline silica dust is widespread in the

U.S. workforce since many industries use or produce materials that contain appreciable amounts of silica. At least 90 occupations have been identified as having the potential for exposure to airborne silica dust (NIOSH, 1980).

Generation of airborne silica dust occurs as a result of four distinct processes.

1. Silica can be an undesired constituent present when a desired substance is obtained. Examples include coal and hard rock mining and refining of metals such as copper, nickel, or gold. Cristobalite or tridymite can be introduced in high temperature processes such as calcining of diatomaceous earth or manufacture of silica brick.
2. Certain industrial processes use material containing silica as part of the in-plant equipment. Examples include the use of sand in abrasive blasting, sand casting in foundries, and certain pyrometallurgical processes.
3. Silica may also be present in natural materials that have commercial value. Examples include sand, granite, and sandstone used in building materials, asphalt, and tombstones. This category could also be extended to include clays such as are used in ceramics and firebrick manufacture.
4. A final category would include the use of silica, often in a relatively pure form, as an ingredient in a mixture to form a final product. This category would include the manufacture of

glass and asbestos cement pipe and the use of silica sand in cement or mortar. Powdered silica flour is used in paints, porcelain, scouring soaps, dental fillings, and wood filler; pure quartz is used in electronic equipment (NIOSH, 1980).

Worker Exposure Levels

Workers have in the past been exposed to excessive airborne free silica concentrations in: metal mining, foundries, the ceramics, pottery and brick industries, the granite industry, in abrasive blasting, and in crushing, grinding, and screening operations.

Several field studies on airborne free silica dust exposures reported since 1960 have been summarized (NIOSH, 1974). U.S. metal miners were exposed to from 0 to 50 mppcf of dust with a quartz content of from 2 to 95 percent. Canadian brick and tile plant workers were exposed to from 1.05 to 4.26 milligrams of respirable dust per cubic foot of air (mg/m^3) containing 13 percent free silica (130 to 550 $\mu g/m^3$ as silica). Vermont granite workers were exposed to from 3 to 5 mppcf dust containing 25 percent quartz, and showed no cases of silicosis over an 18 year period. Other Vermont granite workers were exposed to from 3 to 20 mppcf of dust containing 9 percent quartz in the early 1970's, down from 7 to 42 mppcf in earlier years due to control measures. Workers in U.S. diatomite plants were exposed to less than 8 mppcf dust containing 61 percent cristobalite.

In 1,197 OSHA inspections from 1972 to 1976, 37 percent of 8,423 air samples were found to exceed the OSHA Permissible Exposure Limit (PEL) for free silica (Ryer, 1978). For the period 1977-1979, 31 percent of worksite samples for silica exceeded the PEL for silica (USDOL, 1980). Other recent silica exposures reported between 1974 and 1980 have been summarized (NIOSH, 1980).

Of interest are reports of silicosis in the abrasive cleaner (silica flour) industry. Silica flour is produced by crushing and milling quartz to a very fine particle size. The flour is used in the manufacture of abrasive cleaners (such as metal polish, toothpaste and abrasive soaps), and as a component of paint, molds, concrete blocks and road surfacing mixtures.

Exposure to silica flour in air has been associated with a particularly rapid onset of acute silicosis. Over 98 percent of silica flour particles are <5μm (micrometers) in diameter, and the median diameter has been shown to be 0.9μm. Therefore silica flour dust is virtually 100 percent free silica and virtually 100 percent respirable (Nelson, 1978; NIOSH, 1981).

Several cases of silicosis among workers in silica flour plants in Ontario were studied (Nelson, 1978). Silica air sampling records based on count were converted to a mass basis. It was estimated that exposures averaged from 210-550 $\mu g/m^3$ free silica, and that these exposures resulted in silicosis development in as little as 4 years in some workers. Using 30 years as a working life, it was calculated that occupational silica flour exposure should have a limit of 50 µg/m^3, to avoid development of silicosis in exposed workers (Nelson, 1978). This is the limit first recommended by NIOSH (1974) and reiterated specifically for silica flour in 1981 (NIOSH, 1981).

A review of airborne silica measurements in 27 silica flour production plants with 1,350 employees (Banks, 1981) showed no decline in the proportion of exposures in excess of the exposure limit (100 µg/m^3) between 1975 and 1979. During this period, 53 percent of exposure measurements exceeded the limit.

In another study, 37 percent of workers employed longer than one year in silica flour production were found to have silicosis. Seventy seven of 91 air samples showed airborne silica concentrations in excess of 50 µg/m^3 and 61 of the 91 in excess of 100 µg/m^3 (NIOSH, 1981). Silicosis has also been reported in workers using silica flour to make abrasive cleaners, and as a filler for wood surfaces in furniture manufacture; no dust concentrations were reported (NIOSH, 1980).

In the manufacture of firebrick, two reports of dust levels are 1 to 2 mg/m^3, virtually all silica, and "in excess" of 100 µg/m^3 (NIOSH, 1980). In other reported studies, workers were found to be exposed to between 36 and 75 µg/m^3 free silica in a Canadian foundry; in a ferronickel refinery 27 of 30 samples exceeded 50 µg/m^3 and 3 of 30 exceeded 100 µg/m^3 free silica; and in an asbestos cement pipe manufacturing plant, workers were exposed to from 26 to 32 μg/m^3 of free silica (NIOSH, 1980). Abrasive blasters in open steel fabrication yards were exposed to ambient concentrations of from 2 to 37 mg/m^3 respirable dust containing from 54 to 84 percent free silica. All blasters wore protective hoods. Exposure levels inside hoods were found to be from 235 to 7700 μg/m^3 as silica (Ziskind, 1976).

The literature on silica exposures reported since 1980, as well as earlier reports not included in earlier review documents, was reviewed and summarized. The bulk of the exposure measurements were in foundries, and are summarized in Table 5-1. In other studies of 113 U.S. foundries in 3 states during 1976 to 1981, 860 of 1,884 samples showed silica exposure in excess of the PEL (100 μg/m^3). In 282 other foundries in 21 states, 14.6 percent of the 10,654 workers were exposed to silica in excess of the PEL; in another 205 foundries, 40.6 percent of 1,743 samples exceeded 1.2 x the PEL (Oudiz, 1983).

Silica exposures of abrasive blasters have been summarized (Blair, 1975) for several industries as follows; monument industry - 0.4 to 1.4 x PEL; shipyards - 0.2 to 6.2 x PEL; painting and sand blasting contractors - 0.15 to 21.5 x PEL; primary metals industries - 0.11 to 44.5 x PEL; and airless blasting of primary metals - 0.08 x PEL. A study of steel fabrication sand blasting operations (Samimi, 1976) reported that sand blasters and helpers

Table 5-1: Silica exposure in foundries

Process	Airborne Silica Concentrations, μg/m^3				
	NIOSH, 1978a*		Davis, 1979		Ayalp, 1982
	Ferrous	Non-Ferrous	Pre Control	Post Control	
Charging	10-50	-	-	-	
Melting	35-36	-	-	-	
Pouring	-	<10-60	-	-	
Sand Handling	20-55	-	-	-	2 to 17 x PEL (200 to 1700 μg/m^3)
Mulling	30-50**	-	-	-	
Mold Making	50-60	<10-110	42-88	30-34	1 to 5 x PEL (100 to 500 μg/m^3)
Core Making	-	-	35	38	
Cleaning; shakeout	10-60	<10-60	41	18	1.5 to 21 x PEL (150 to 2100 μg/m^3)
Chipping, grinding	30-110	-	75	66	

* concentrations following installation of controls; no pre-control figures available

** 70% cristobalite

SOURCES: A. Ayalp and Myroniuk, D., "Evaluation of Occupational Exposure to Free Silica in Alberta Foundries," *Am. Ind. Hyg. Assoc. J.*, 43(11):825-831, 1982.

J. W. Davis, "The Use of Sand Substitution to Solve the Free Silica Problem in Foundry Atmospheres," *Am. Ind. Hyg. Assoc. J.*, 40(7):609-618, 1979.

U. S. Dept. of Health Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, "An Evaluation of Occupational Health Hazard Control Technology for the Foundry Industry," DHEW(NIOSH) Publication No. 79-114, 1978.

were exposed to from 547 to 3,196 $\mu g/m^3$ silica, while painters, welders and other workers were exposed to from 124 to 213 $\mu g/m^3$. Crane operators were exposed to 60 $\mu g/m^3$ silica.

Chen (1983) reported respirable silica exposures in various mining operations as measured by Mine Safety and Health Administration inspectors during 1977-1981. Sixty-five percent showed free silica exposures <50 $\mu g/m^3$; and 95 percent were <280 $\mu g/m^3$. Exposures in molybdenum and clay shale mining were the highest found; 95 percent of samples were <1,500 $\mu g/m^3$ in molybdenum mining and <380 $\mu g/m^3$ in clay shale mining. The 95 percentile concentrations were reported because the purpose of the study was to determine statistically the dust reduction necessary to achieve several candidate exposure limits. Lowest silica exposures found were in limestone mining, where exposures varied between 20 and 170 $\mu g/m^3$, the highest levels being in drilling, blasting, and finishing of the limestone.

Five percent of 1,220 silica samples taken in 16 portland cement plants employing 2,485 workers exceed 100 $\mu g/m^3$, and 10.8 percent exceeded 50 $\mu g/m^3$ (Sanderson, 1983).

Non-occupational silica exposures have also been measured. Autopsies on 98 urban dwellers showed 0.235 mg silica per gram of dry tissue, as compared to 2.08 mg/gm reported in the lungs of West Virginia coal miners (Sweet, 1978).

CHAPTER 6

CONTROL OF EXPOSURE TO AIRBORNE SILICA DUST

Introduction

Silicosis is an entirely preventable disease. It is caused by inhalation and retention in the lungs of fine crystalline silica dust, and can be prevented by controlling exposure to such dusts. The technology for controlling worker exposure to airborne silica dust has been known and used for decades.

This chapter describes the mode of silica dust exposure to workers, the conventional concepts of reducing exposure to dust, the OSHA strategy for compliance with standards, and discusses recent published evaluations on the degree of success achieved by specific silica dust controls in a variety of industries.

Mode of Exposure

Whenever materials containing crystalline free silica are processed, there is opportunity for silica dust to become airborne. Several examples of such "dusty" processes are given in Chapter 5. Processes involving abrasion (sand blasting, grinding, milling, etc.) create dusts of particularly small particle size ($< 5\mu m$ diameter).

These dust particles are the primary hazard for silicosis. They are too small to be easily seen as a "cloud"; they are too small to settle, and so remain airborne; and they are "respirable"; that is, small enough to pass through the upper respiratory passages

Table 6-1: Contents of Control of Silica Exposure

- SUBSTITUTION
- ENGINEERING CONTROLS
  - Process Change
    - Material form
    - Facilities/equipment
  - Isolation
    - Enclosure
    - Automation
    - Distance
  - Ventilation
    - Control at source (local)
    - Dilution
- PERSONAL PROTECTION
  - Respirators
  - Clothing
  - Personal Hygiene
- ADMINISTRATIVE CONTROLS
  - Worker and Supervisor Training
    - Hazard recognition
    - Work practices
  - Other Managerial Controls
    - Worker rotation
    - Hazardous job timing
    - Maintenance
    - Housekeeping
    - Policy Enforcement

and be deposited in the alveolar spaces of the lungs. Control measures to prevent exposure to hazardous silica dust must eliminate or control these small particles which tend to remain airborne.

Concepts of Control

Methods for controlling workplace hazards may be classified in several ways (Peterson, 1973; NIOSH, 1974). For purposes of this report, control concepts have been classified in Table 6-1 as Substitution, Engineering controls, Personal Protection and Administrative controls.

Substitution

The most direct method of eliminating silica dust is to substitute other less hazardous material for silica-containing material. This control has been widely used in abrasive blasting operations and to some extent in foundries. A number of silica-sand substitutes are available for abrasive blasting, including metallic shot and grit, garnet, nut shells, cereal husks, and sawdust (NIOSH, 1974). Olivine (magnesium iron silicate) has been used for mold making in foundries to reduce silica dust exposure (Davis, 1979). Substitutes containing other, perhaps more hazardous, substances should not be used.

Process Change

Substitution of a less dust-producing process for a dusty process is also used to control silica dust. The addition of water during material processing is widely used as a dust suppressant in many industries. Examples are use of water sprays in mines (ILO, 1976), the addition of moisture to molding sand in foundries (Shaw, 1981b) wet sawing of granite (Hickey, 1978), and wet processing of portland cement (Sanderson, 1983). Such sprays, while suppressing visible dust, may be of limited value in suppressing the smaller more hazardous respirable silica dust particles (NIOSH, 1974).

Less dusty processes which may be applicable to foundries are the cleaning of castings by the salt bath process, acid pickling or ultrasonic cleaning, as an alternative to abrasive cleaning. The use of water jetting and laser cutting for removal of excess metal from castings have been considered as alternates to chipping and grinding (Shaw, 1981).

Process change usually requires some equipment or facility substitution. However, equipment and facility substitutions may be employed independent of process changes. Examples are use of vacuum cleaning instead of compressed air cleaning, paving and wetting of dusty travel surfaces, and use of screw conveyors instead of pneumatic conveyors.

Isolation

Isolation of a process is the placement of a barrier between the process and the worker. There are three basic means of isolating a dusty operation: enclosure of an operation to prevent the escape of dust to occupied areas, or placement of the operator in an enclosed cab or room; automation, the use of unattended machines to perform a dusty process; and distance, the placement of dusty operations remote from workers. Examples of isolation are enclosure of an abrasive blasting operation in a ventilated booth; automation of a shakeout system in a foundry; or performance of open-air sandblasting at a distance from other worksites.

Ventilation

Where the prevention or isolation of a hazard cannot be achieved, industrial ventilation has proved to be an effective means of protecting workers from excessive dust exposure. Industrial ventilation may be briefly defined as the control of contaminants at the workplace by the movement of air.

Ventilation for silica dust control may be utilized in two ways: control at the source (or local exhaust ventilation), and general (or dilution) ventilation. Local exhaust ventilation aims to protect the worker by capturing the dust in an exhaust air stream as it is generated, and discharging it elsewhere. Examples are laboratory fume and kitchen range hoods, both of which use fans to promote exhaust air flow. Dusty operations are often placed in hoods with minimal openings to obtain maximum control with minimal exhaust air volume. General or dilution ventilation aims to protect the worker by providing sufficient clean air to dilute the dust concentration to a safe level, and to promote a general air flow in a direction away from the worker toward the dusty operation.

Neither local nor general ventilation acts to prevent generation of dust, but only to capture or dilute dusty air and take it to another location. The air may still have to be cleaned before discharge to the ambient environment, to meet Environmental Protection Agency or other ambient air standards. Several publications (ACGIH, 1982a; NIOSH, 1976; NIOSH, 1976a) describe how ventilation may be used for dust controls. General (or dilution) ventilation is appropriate for control of silica exposure only in outdoor situations, and there only where dusty operations can be placed downwind or isolated by distance from occupied worksites.

Personal Protection

Respiratory protection is often required to avoid silica exposure where excessive concentrations occur in locations where other means of control are not feasible. NIOSH (1974) has specified the types of respirators required for adequate protection from various air concentrations of silica. Protective clothing and personal hygiene are indicated to prevent the exposed worker from generating silica dust from his clothing after leaving work. Face, eye and body protection against injury (not silicosis) are also required in abrasive blasting operations. OSHA has general regulations for respiratory protection programs in industry, and specific regulations for use of respiratory protection, ventilation, and protective clothing in abrasive blasting (OSHA, 1981).

Respirators are considered to be a limited means of protection, as their effectiveness is dependent on worker cooperation and training in their use, and in proper fit testing and maintenance. Studies have shown that respirators often give inadequate protection against silica exposure (Ziskind, 1976).

Respiratory protection is traditionally considerd to be a less expensive means of controlling exposures than engineering controls, and one which can be implemented relatively quickly. Because of this, employers often prefer respirators to installation of engineering controls.

Administrative Controls

NIOSH (1974) and others recommended several ancillary measures aimed at reducing silica exposure. Training aims to educate managers and workers on the hazards of silica dust inhalation, the proper use of personal protection equipment, and the recognition of hazardous situations. Training in proper work practices is considered important in preventing generation of airborne silica dust. Practices include following dust suppressant procedures (such as vacuum instead of compressed air cleaning), keeping enclosed operations properly closed, maintenance, and housekeeping.

Other managerial procedures are rotation of workers in dusty areas so that no one person is exposed full-time, and scheduling of particularly dusty procedures (such as cleaning or maintenance) to take place on weekends or at other times when few workers are present.

An underlying factor in the success of managerial controls is the adoption and enforcement of dust control policies. Company dust control policies are often enforced less vigorously than are policies for the wearing of hard hats, or no smoking rules in flammable substance areas. This is probably because it is much easier to relate cause and effect to an immediate explosion due to careless smoking, than to relate severe respiratory problems to ten years' previous employment in a quarry.

Regulatory Compliance Strategy

The Occupational Safety and Health Administration (OSHA) has established industrial occupational Permissible Exposure Limits (PELs) for many substances, including silica dust (OSHA, 1981). Current OSHA general air contaminant standards require that employers implement feasible engineering controls to maintain air contaminant concentrations in the workplace to within the prescribed PELs. Because of the limited protection provided by respirators, their use is permitted only in those cases where engineering controls are not feasible, are not yet installed or are not adequate (OSHA, 1983).

OSHA is reviewing its policy relating to the use of engineering controls and respirators for air contaminants. Current policy has been criticized as being too inflexible, not cost-effective and often unnecessary for health protection. OSHA intends to perform a careful review of the relevant issues and to consider, as a first action, the possible revision of two standards, 29 CFR 1910.1000(e) (Air Contaminants) and 29 CFR 1910.134(a)(1)(Respiratory Protection) (OSHA, 1983).

Specific OSHA standards for several substances (asbestos, lead, etc.) have additional provisions such as air contaminant monitoring, removal of certain specified workers to other jobs, and required work practices.

OSHA has emphasized the importance of controlling silica exposure by including silica as a "Target Health Hazard" in its target health hazard program in 1972 (Ryer, 1978), and by including silica control in foundries in the National Emphasis Program in 1975 (BNA, 1975).

OSHA has for some years been considering a specific standard addressing use of silica sand in abrasive blasting, and in 1978 conducted a technological feasibility assessment and economic impact analysis for such a standard (Hickey, 1978). The study considered three alternatives: banning use of silica sand in abrasive blasting; setting minimum criteria on size and hardness of blasting sand; and controlling exposure through work practices. The 1978 annualized costs of the three alternatives respectively were estimated to be $236 million; $28 million and $191 million (Hickey, 1978). The proposed OSHA standard on abrasive blasting has not been promulgated to date.

Great Britain banned the use of silica sand for abrasive blasting in 1948 and NIOSH has recommended a similar prohibition in the U.S. (NIOSH, 1974). Sweden banned silica as an abrasive in manual abrasive blasting in 1981 (SW, 1983). A California standard requires that, prior to use, abrasive sand may not consist of more than 1 percent by weight of grain size which will pass a number 70 U.S. standard sieve (0.3 mm) and, after use, it may not consist of more than 1.8 percent by weight of particles 5 μm or less in diameter (Hickey, 1978).

Evaluation of Silica Dust Controls

Substitution

In abrasive cleaning, substitution of non-silica abrasives for silica sand eliminates airborne silica dust unless the material being cleaned contains silica, as in the case of large castings from silica sand molds (Blair, 1975; Hickey, 1978).

In foundries much silica dust is generated during cleaning, chipping and grinding of castings because some sand from the cores and molds remains on the castings, and is usually removed by abrasive cleaning, which generates airborne silica dust. If abrasive cleaning is performed by sand blasting, silica dust may be generated from both the blast sand and the mold and core sand.

Use of non-silica olivine sand for making molds in a ferrous foundry was found to reduce respirable free silica exposures by from 25 to 61 percent during the year following its introduction, not only in the molding area but also in the areas where castings are removed from molds (shakeout) and ground or polished (grinding) (Davis, 1979). Exposures in the core shop, which continued use of silica sand, were not reduced. Recontamination of the olivine sand with silica sand used in other parts of the foundry later increased silica exposure levels. This latter phenomenon has occurred in other foundries (Ayalp, 1982), and in one instance, an increased silica exposure after introduction of olivine sand was reported (NIOSH, 1980). It is evident that partial substitution of non-silica sand, in a foundry, while continuing some use of silica sand, is not a satisfactory long-term control.

Another study (NIOSH, 1978a) concluded that use of non-silica molding sand could reduce the silica content of dust by 80 percent, but would not eliminate the need for exhaust ventilation at dusty operations. The toxicity of olivine relative to silica has not been established (NIOSH, 1978a).

Process Change

Substitution of wet processing and spraying for dry operations has been widely used to control silica dust. Spraying is a primary means of dust control in mining, but is considered to be inadequate alone and is usually used in conjunction with ventilation as a control (ILO, 1976; Rodgers, 1983). By contrast, wet processing in the manufacture of portland cement appeared to have no effect on respirable dust levels (Sanderson, 1983).

In foundries, the addition of moisture to sand has been found to reduce dust concentrations substantially (NIOSH, 1978a; Shaw, 1981a). The wetting of bulk material before processing may be more effective as a dust control than spraying in dusty areas, because the spray may not eliminate the smaller respirable silica particles from the air (NIOSH, 1974).

Isolation

Isolation by enclosure and automation has been used effectively to reduce silica exposure in foundries (NIOSH, 1978a; Ohman, 1978; NIOSH, 1981a). Abrasive cleaning in ventilated booths control dusts from the process. Remote control of shakeout permits the operator to remain in an enclosed booth with a protected air supply. Enclosure of sand conveyors prevents escape of dust from this source. Location of the molding operation remote from other foundry operations reduces airborne silica concentrations in some areas.

Ventilation

In an extensive study of foundries (NIOSH, 1978a), it was concluded that ventilation is not now being used effectively in some foundry areas, due to limited use and misapplication. Application of recommended local ventilation guides (ACGIH, 1982a) were found to provide effective control where properly used (NIOSH, 1978a; Ayalp, 1982). The exposure levels presented in Table 5-1 (first column) were achieved primarily with local ventilation. Improved local ventilation decreased dust exposure in a Swedish foundry by from 75 to 80 percent (Ohman, 1978). Ventilation is a primary dust control method in mines (ILO, 1976).

Respiratory Protection

Respiratory protection is important for abrasive blasters using silica sand (NIOSH, 1974) and workers handling silica flour (NIOSH, 1981). This is because such a large percentage of the silica dust generated in these operations is respirable. Silica flour operations have been identified comparatively recently as very hazardous (NIOSH, 1981), but several studies have been performed on respiratory protection in abrasive blasting (Blair, 1975; Samimi, 1975, 1976; Ziskind, 1976). These studies generally show that abrasive blasters, their helpers, and even other nearby workers are often overexposed to silica. The blasters themselves usually wear blasting helmets for protection from injury from flying sand but may not wear respirators beneath the helmets. Further, where air-supplied respirators are used, the supply air may not be protected from silica dust contamination. Helpers and nearby workers may wear no protection and thus be exposed to smaller invisible airborne silica particles outside the sphere of the visible dust cloud (Hickey, 1978). The general ineffectiveness of respiratory protection in abrasive blasting appears to some extent in other dusty operations, where respirators have not traditionally been worn, or, if worn, may be removed frequently due to discomfort, reducing their effective protection.

Summary

There is adequate conventional technology available for controlling silica exposure, through the use of substitution, process change, isolation, ventilation, respiratory protection and administrative controls. The control technologies have been known for decades. The consensus of many studies is that these controls are not being applied effectively in many cases, perhaps due to: lack of awareness of need; cost of control; improper application; or difficulty in keeping the controls effective from a maintenance standpoint.

The many studies on control of silica exposure stress the importance of proper maintenance, housekeeping, and other individual work practices in keeping silica exposures low, regardless of the engineering controls in place.

Obstacles to achieving effective silica dust control and strategies for achieving control are discussed in Chapters 8 and 9.

CHAPTER 7

REGULATORY CONTROL AND MEASUREMENT OF SILICA DUST EXPOSURE

Regulatory Control

The development of industrial hygiene exposure values for quartz is based on the concept that the acceptable level of airborne dust is inversely related to the concentration of quartz in the dust. That is, less exposure is allowed as the percent silica increases. Dusts containing less than one percent quartz are generally classified as nuisance, or inert, dusts. Table 7-1 depicts the exposure limits in use during various time periods.

During the late 1930s to mid-1940s individual states developed guidelines for exposure to silica in their respective industries. Samples were collected in impingers and reported in millions of dust particles per cubic foot of air (mppcf). For example, Vermont adopted a maximum allowable concentration (MAC) of 10 mppcf for the granite industry (Ashe, 1964); North Carolina recommended an MAC of 25 mppcf for its granite workers (NC, 1938) and developed a scale of MACs for foundry workers, depending upon the percent quartz in the dust in each segment of production (Trice, 1938).

The American Conference of Governmental Industrial Hygienists (ACGIH) was the first national organization to compile a list of recommended limits for workplace exposure to chemical and physical agents (ACGIH, 1946). Initially called MACs, the term Threshold

Table 7-1: U.S. Exposure Limits for Silica-containing Dust[a]

	ACGIH-TLV Total Dust Count Limit, mppcf			Mass Limit, mg/m^3 Resp. Dust	
Percent Silica	1950-1961	1962-1969	1970-present	ACGIH-TLV; OSHA-PEL*	NIOSH Rec.**
0	50	50	30	5	-
1	50	42	27	3.3	5
2	50	36	25	2.5	2.5
5	20	25	20	1.4	1.0
10	20	17	15	0.8	0.5
20	20	10	10	0.45	0.25
50	5	4.5	5	0.19	0.10
100	5	2.4	2.7	0.10	0.05

[a] OSHA limits are regulatory; others are recommended.

* Divide by 2 if silica is in the form of cristobalite or tridymite.

** The NIOSH recommended limit for respirable silica exposure, stated in terms of respirable dust is. resp. dust limit = $5/(\%SiO_2)$, mg/m^3.

SOURCES: Fairhall, 1950
ACGIH, 1962
ACGIH, 1968
ACGIH, 1970
OSHA, 1981
NIOSH, 1974

Limit Value (TLV) was later adopted (Fairhall, 1950). Three values were given for quartz, depending upon the percent silica content:

SiO_2 Content (%)	MAC (mppcf)
<5	50
5-50	20
>50	5

A review of investigations by the U.S. Public Health Service and others indicated that results of these exposure-response studies were reasonably consistent with a TLV expressed as:

$$\text{TLV (in mppcf)} = 250/(\%SiO_2 + 5)$$

This change in recommended limits on airborne dust was made in 1962 (ACGIH, 1962). In 1970, the TLV equation for silica exposure was made consistent with the new TLV for nuisance dust by the following change

$$\text{TLV (in mppcf)} = 300/(\%SiO_2 + 10) \quad \text{(ACGIH, 1970).}$$

The development of the mass-respirable cyclone-filter assembly in the 1960s made available a simpler, more accurate, and more rapid method of measuring silica dust exposure. In order to correlate new mass sampling data with older count sampling data, it was necessary to develop a relationship between data based on count and mass. Paired sampling conducted in a Barre, Vermont, granite shed resulted in development of an exposure limit, based on mass, considered to be consistent with the TLV based on count. This was:

TLV (in mg/m^3) = 10/(% respirable quartz + 2) (Sutton, 1968). The percent respirable quartz is that found in the dust fraction passing through a size-selective cyclone. The factor of 2 is added to the denominator to limit the TLV for respirable dusts containing one percent quartz or less to 5 mg/m^3. ACGIH listed this limit as an intended change in the TLV for silica in 1968 (ACGIH, 1968). The 1968 ACGIH recommended TLVs were adopted as standards under the Walsh-Healy Act and were later made mandatory exposure limits by the Occupational Safety and Health Administration (USDOL, 1981). Similar standards for silica exposure in mining have been adopted by and are enforced by the Mine Safety and Health Administration (USDOL, 1982).

Recent work has centered on determining the mass of airborne quartz to which an employee may be exposed throughout a 10-hour workday, 40-hour workweek, over a working lifetime without adverse health effects. In 1974 the National Institute for Occupational Safety and Health (NIOSH) recommended limiting silica exposure to 50 micrograms per cubic meter of air ($\mu g/m^3$). The studies on which NIOSH based its recommendation used pulmonary function performance as the measure of health effect (Theriault, 1974, 1974a, 1974b). Pulmonary function testing is considered to be a more sensitive indicator of silicosis than X-ray.

Measurement of Exposure

The three sampling techniques most widely used in the past and present to collect environmental dust exposure data are the

Greenburg-Smith impinger, the midget impinger and the cyclone-filter assembly. In the impinger, air is drawn through a glass tube and impacted at high velocity onto a wetted surface perpendicular to the direction of air flow. The change in direction of the air stream and the inertia of particles results in deposition of the particles on the collection surface. Impingers may be electrically or manually powered. The high flow rate required for the Greenburg-Smith impinger, 28.3 liters per minute (lpm), generally necessitated electrical means. Samples were usually collected by placing the impingers on stands or holding them near the worker during performance of representative tasks. The glass construction and 100 cubic centimeters (cc) of fluid sampling media made it difficult to collect samples representative of the air breathed by the worker ("personal" samples).

The midget impinger replaced the Greenburg-Smith in the early 1940s. This instrument is smaller, holding 10 cc of fluid, and is easily adapted to a battery- or manually-operated pump to maintain the 2.8 lpm flow rate for a 15-minute sampling period.

Analysis of impinger samples followed U. S. Public Health Service protocols (Bloomfield, 1935). Two 4 cc samples of the impinger fluid were pipetted into Sedgwick-Rafter counting cells, or their equivalent. After allowing 20 minutes settling time, particles less than 10 micrometers (μm) in diameter were counted in 10 microscope fields. The concentration in the sampled air was calculated from the average of these 10 fields. An employee's time-weighted average daily exposure was estimated by observing the amount of time spent at various activities and summing exposures over the entire work shift.

Results, reported in millions of particles per cubic foot of air (mppcf), represented total dustiness. An attempt to compensate for this lack of specificity for the silica component was made by allowing different levels of dustiness, depending upon the silica content of the parent material or the settled dust. Neither parameter is necessarily the same as the silica content of the airborne dust (Hatch, 1936). Errors in the dust count technique are large. Ayer (1966) and Roach (1967) estimated the coefficient of variation of counting to be 13 to 20 percent.

The midget impinger has been shown to be virtually 100 percent efficient in the collection of particles [illegible] µm in diameter. Efficiency falls to 80 percent at 2 µm and 75 percent at 3 µm. Particle collection efficiency decreases rapidly as particle diameter falls below 1 µm, reaching zero percent at about 0.2 µm (Davies, 1951). This is of little consequence, however, since the resolution of the light field counting method is about 1 µm (Brown, 1938).

The above considerations, coupled with the fact that not all 10 µm particles are deposited in the lower portion of the respiratory tract, contributed to development of the cyclone-filter assembly (Lippmann, 1970) which is now the method of choice. This device is small, and may be worn by an employee throughout a work shift, making it simple to collect representative personal samples. Power is supplied by a battery-operated pump attached to the worker's belt

This device collects particles which have a high probability of reaching the lung; that is, "respirable" particles. In sampling, air is passed through a cyclone pre-sampler to remove the larger particles. The cyclone takes advantage of radial force to effect particle separation; the geometry of the unit determines the percent removal of a given size of particles from the air stream. The material passing through the cyclone is collected on a filter. This respirable fraction is weighed to determine mass concentration of silica in the air, and the percent silica content is det.rmined by one of several techniques. Results are reported in milligrams per cubic meter (mg/m^3) of respirable dust with an accompanying silica content in percent.

The Talvitie wet chemistry (Talvitie, 1964) and infrared spectrophotometry (NIOSH, 1977) methods are most frequently used for silica analysis. Results from the Talvitie method are strongly dependent on operator attention to a rigid, carefully timed analytical protocol; also, the method is incapable of distinguishing the individual silica polymorphs, i.e., quartz, tridymite and cristobalite. The infrared procedure, widely used for quartz, has been shown to be dependent on the particle size of the sample (Mangia, 1975).

NIOSH (1974) advanced the use of X-ray diffraction to compensate for these problems. The NIOSH Proficiency Analytical Testing (PAT) program involves bi-monthly analysis for silica by 79 reference laboratories in the U.S., using the colorimetric, X-ray diffraction, and infrared methods. Results achieved by the three methods are comparable; the X-ray diffraction method achieves a 6 to 8 percent variation of results within laboratories, and is more exact, reproducible, and less labor intensive than the other methods (NIOSH, 1983).

CHAPTER 8

OBSTACLES TO CONTROLLING SILICA EXPOSURE

Introduction

It is estimated that a minimum of 59,000 cases of silicosis may be expected to develop, based on current silica dust exposure levels and numbers of exposed workers (DOL, 1980), despite the fact that the technology and procedures necessary to avoid inhalation of silica are well known. What then are the obstacles to controlling silica dust in new and existing workplaces? This chapter discusses briefly some of the policy and technological factors which have emerged as obstacles, and, where evident, means by which they may be overcome.

Policy Issues

The Department of Labor (DOL, 1980) has identified three major policy issues which require attention, specifically, (a) the limited availability of epidemiologic data to establish health standards and defend them in legal and economic terms, (b) the contentious nature of the standard-setting process, and (c) the lack of sufficient economic incentives for firms to reduce exposures to health hazards. The Department of Labor is developing management strategies to address these issues.

An additional issue is the sheer magnitude of the task of monitoring silica exposure. Of the estimated 25 million workers exposed to OSHA-regulated hazards, only 500,000 are in worksites inspected by Federal OSHA inspectors in any one year. OSHA may not prudently neglect other hazards to concentrate their inspection force on silica problems.

Reliance on After-the-fact Controls

A striking fact which emerges from the review in Chapter 6 is that, except for material substitution, most current conventional controls stress capturing, containing, or removing silica dust after it is generated. Two reports (NIOSH, 1978a; NIOSH 1981a) stress the need to focus on alternative advanced methods aimed at complete prevention of the generation of silica dust.

Difficulty in Measuring Exposure

Chapter 7 describes the past and current methods of measuring silica dust in air, which are at best tedious. Analysis is further complicated by the fact that different forms of silica, which have different exposure limits, must be identified. For example, OSHA currently does not perform tridymite analyses on air samples taken for compliance purposes, and samples are analyzed for cristobalite only upon request (OSHA, 1982).

Inconsistencies in Silica Standards

Due in part to its history of development, there are two inconsistencies in current silica exposure limits. The first is that the limits are not usually stated in terms of silica but rather in terms of respirable dust. The second is that, when the exposure limits in various regulatory and recommended standards are stated in terms of silica, they are different. Table 8-1 states limits in terms of respirable silica, and illustrates these differences which though not large are probably confusing. Only one recommended limit (NIOSH, 1974) is internally consistent.

Another complicating factor is that the limits themselves may be open to question. As discussed in Chapter 7, current "mass" limits are based on conversion from previous "count" limits, largely from conversion ratios found in the Vermont granite industry, which may not apply to other industries (Nelson, 1978; Rice, 1983). Many current cases of silicosis may reasonably be attributed to higher past exposures above current limits (DOL, 1980).

The American Conference of Governmental Industrial Hygienists has concluded that in documented examples of virtual silicosis elimination (no cases among newly exposed persons), exposures have been well below the recommended exposure limit. ACGIH suggests that quartz concentrations in air be maintained as low as current practices will permit.

NIOSH (1974) has resolved the inconsistencies in exposure limits by recommending a limit of 50 $\mu g/m^3$ as silica. This limit has been supported by other studies (Ohman, 1973; Nelson, 1978). In sum, simplification of the silica exposure limit itself may remove an obstacle to its achievement.

Table 8-1: Derived Silica Exposure Limits

% Quartz in Respirable Dust	Exposure Limit in Terms of Silica ($\mu g/m^3$)						
	OSHA-PEL[a]		ACGIH-TLV		MSHA[a]		
	Coal Dust	Other Dust	Coal Dust	Other Dust	Coal Dust	Other Dust	NIOSH
1	24	33*	20	33*	20	20	50
2	48	50*	40	50*	40	40	50
5	120	71*	100	71*	100	100	50
10	83	83*	83	83*	100	83**	50
20	91	91*	91	91*	100	91**	50
50	96	96*	96	96*	100	96**	50
100	98	98*	98	98*	100	98**	50

[a] Different standards apply for silica contents of <5 and >5 percent.

* Divide by 2 if silica form is tridymite or cristobalite.

** Divide by 2 if silica form is cristobalite.

SOURCES:	OSHA-PEL:	U.S. Department of Labor, Occupational Safety and Health Administration, General Industry OSHA Safety and Health Standards, Publication No. OSHA 2206 Revised, June 1981.
	ACGIH-TLV:	American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1982, Cincinnati, OH, 1982. (ACGIH is considering stating limits in terms of silica.)
	MSHA:	U.S. Department of Labor, Mine Safety and Health Administration, Subchapters N and O, Metal and Non-Metal Mine Safety and Health, and Coal Mine Safety and Health. 30 CFR, 55, 56, 57, 70 and 71, Washington, DC, 1982.
	NIOSH:	U.S. Dept. of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Criteria for a Recommended Standard-Occupational Exposure to Crystalline Silica, HEW Publication No. (NIOSH) 75-120, 1974.

Variety of Exposure Conditions

The wide variety of silica exposure situations presents obstacles to its control. This problem is exemplified by the specific exposure problem from abrasive blasting with silica sand, complicated by the fact that it is widely used in the construction industry, primarily in open-air, temporary worksites which are not amenable to fixed engineering controls (Hickey, 1978). As discussed in Chapter 6, Regulatory Compliance Strategy, current OSHA regulations covering abrasive blasting are diverse and separated. OSHA has addressed this problem by proposing a separate standard covering abrasive blasting (BNA, 1980). The Advisory Committee on Construction Safety and Health has recommended that still another separate standard be established for abrasive blasting in the construction industry (BNA, 1980a). The enforced reliance on respirators in situations where engineering controls are not feasible introduces further dependence on personal protective devices.

Unawareness of Hazard

"Unawareness" of the silica exposure hazard may be manifest in several ways. Managers and workers may know silica is hazardous but be unaware that workers are being exposed; workers may know they are exposed but not know silica is hazardous; or workers may believe they are protected when they are not. The workers also may be in an occupation which has not yet been identified with excessive silica exposure (NIOSH, 1980; NIOSH, 1981; Banks, 1981). For

468

example, silica flour has been mislabeled as amorphus silica, a relatively harmless form (NIOSH, 1981), to the probable detriment of subsequent users. Education of both employers and employees to the hazards of silica exposure, the proper use of exposure controls and respirators, and detection of exposure sources appear indicated.

CHAPTER 9

STRATEGIES FOR SILICOSIS PREVENTION

Introduction

There are many strategies for the control of silica exposure and prevention of silicosis. This chapter will focus primarily on scientific and technological strategies, and to some extent on policy and administrative strategies.

Worker education, housekeeping, publicity about the hazards of silica, and other engineering and administrative controls will still be necessary to prevent exposure, and new developments should be considered as additional controls, not replacements.

Exposure Prevention Technology

One basic control strategy is to develop new means of preventing the generation of silica dust, as contrasted to refining current methods for avoiding exposure to such dust after it is generated. This strategy requires expansion of efforts in the areas of substitution and process change.

Silica sand substitutes for abrasive blasting are now available at 3 to 4 times the cost of silica sand, but current production is less than 10 percent of the amount needed (Hickey, 1978). Banning the use of silica sand for abrasive blasting, as recommended by NIOSH (1974) could create more incentive for development of a sufficient supply of alternative abrasives at lesser cost differential, and also encourage development of abrasives which will impart a finish of the same characteristics as that provided by silica sand.

In foundries, advanced technology is being directed toward sand substitutes in molds and cores, non-dusty techniques for cleaning and finishing, and addition of moisture to sand to avoid dust generation (NIOSH 1978a, 1981a). Refinement of current technology to specific applications is still necessary and should not be neglected.

Determination of Health Effects Threshold

As described in the previous chapters, there is some degree of uncertainty as to what constitutes a "safe" level of silica exposure, and whether silica is carcinogenic.

Research to resolve these questions would permit exposure control efforts to be focused directly toward prevention of health effects rather than toward an unverified exposure level.

The long exposure periods often associated with manifestation of health effects, especially with carcinogens, argues against withholding refinement of current exposure limits until such determinations are made.

Determination of Silica Exposure

Current methods of determining silica content of dust samples are tedious and time-consuming. Development of a simplified, rapid and accurate method for silica determination would enhance both control of silica exposure and research on determination of its health-effects threshold and dose-effect relationship.

Unification of Exposure Limits

Chapter 8 described the various existing limits for silica exposure and the indirect basis on which compliance is determined. Unification of the exposure limit to a single standard based directly on silica itself would remove some of the confusion surrounding application of current limits. There remains the possibility that different limits are needed in different occupations. However, the differences in current limits are not based on evidence of such need, and these differences appear to be unnecessary.

Early Health Effects Detection

Currently, medical evidence of health effects of silica exposure does not occur early enough to permit reversal of the effects. Research into means of detecting physiological changes at a reversible stage is a strategy which should be explored.

Respirator Effectiveness and Acceptability

In some occupations (i.e., hand-held abrasive blasting), respiratory protection is the only feasible means of reducing silica exposure. Although there has been much improvement in respirator effectiveness, comfort and acceptability in the last decade, respirators still at best provide vulnerable protection, and further improvement in both effectiveness and acceptability is needed. For example, built-in microphones would permit voice communication without respirator removal, small built-in radios would permit remote communication of instructions or hazard warnings.

CHAPTER 10

REFERENCES AND GLOSSARY

References

ACGIH, 1946: American Conference of Governmental Industrial Hygienists, Proceedings of the Eighth Annual Meeting, Chicago, IL, April 7-13, 1946.

ACGIH, 1962: American Conference of Governmental Industrial Hygienists, Threshold Limit Values for 1962, adopted at 24th Annual Meeting, Washington, DC, May 13-15, 1962.

ACGIH, 1966: American Conference of Governmental Industrial Hygienists, Documentation of Threshold Limit Values, 2nd ed., Cincinnati, OH, 1966.

ACGIH, 1968: American Conference of Governmental Industrial Hygienists, Threshold Limit Values of Airborne Contaminants for 1968 - Recommended and Intended Values, adopted at 30th Annual Meeting, St. Louis, MO, May 13, 1968.

ACGIH, 1970: American Conference of Governmental Industrial Hygienists, Threshold Limit Values of Airborne Contaminants and Intended Changes, adopted by ACGIH for 1970, p. 18, Cincinnati, OH, 1970.

ACGIH, 1982: American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances and

Physical Agents in the Work Environment with Intended Changes for 1982, Cincinnati, OH, 1982.

ACGIH, 1982a: American Conference of Governmental Industrial Hygienists, Committee on Industrial Ventilation, Industrial Ventilation, 17th ed., 1982.

ACGIH, 1982b: American Conference of Governmental Industrial Hygienists, Documentation of the Threshold Limit Values, 4th ed. Cincinnati, OH, 1982.

Ashe, 1964: Ashe, H. B. and Bergstrom, D. E., "Twenty-six Years' Experience with Dust Control in the Vermont Granite Industry," Ind. Med. & Surg. 33(2):73-78, 1964.

Ayalp, 1982: Ayalp, A. and Myroniuk, D., "Evaluation of Occupational Exposure to Free Silica in Alberta Foundries," Am. Ind. Hyg. Assoc. J. 43(11):825-831, 1982.

Ayer, 1966: Ayer, H. E., "Problems of Dust Counting," Transactions of the 28th Annual Meeting of the American Conference of Governmental Industrial Hygienists, pp. 11-21, Pittsburgh, PA, 1966.

Baily, 1974: Baily, W. C., Brown, M., Buechner, H. A. et al., "Silico-mycobacterial Disease in Sandblasters," Amer. Rev. Respir. Dis. 110(2):115-125, 1974.

Banks, 1981: Banks, D. E., Morring, K. L., and Boehlecke, B. A., "Silicosis in the 1980's," Am. Ind. Hyg. Assoc. J. 42(1):77-79, 1981.

Banks, 1981a: Banks, D. E., Morring, K. L. Boehlecke, B. A. et al., "Silicosis in Silica Flour Workers," Am. Rev. Resp. Dis. 124(4): 445-450, 1981.

Blair, 1975: Blair, A. W., "Abrasive Blasting Protectice Practices Study - Field Survey Results," Am. Ind. Hyg. Assoc. J. 36(10): 745-751, 1975.

Bloomfield, 1935: Bloomfield, J. J. and DallaValle, J. M., "The Determination and Control of Industrial Dust," Public Health Bulletin, No. 217, pp. 40-43, 1935.

BNA, 1975: Bureau of National Affairs, Current Report, 5(24):829, November 13, 1975.

BNA, 1980: Bureau of National Affairs, Current Report, 9(44):1022, 1039-1047, April 3, 1980.

BNA, 1980a: Bureau of National Affairs, Current Report, 9(51): 1185-1186, May 22, 1980.

Brown, 1938: Brown, C. E., Baum, L. A. H., Yant, W. P. et al., "Microprojection Method for Counting Impinger Dust Samples," U. S. Bureau of Mines Report of Investigation, No. 3373, 1938.

Chen, 1983: Chen, C. K., Katt, R. J., Hamrick, M. L., et al., "Technological Feasibility of Controlling Asbestos and Silica at Mines and Mills," paper #33 presented at the American Industrial Hygiene Conference, Philadelphia, PA, May 23, 1983.

Davies, 1951: Davies, C. N., Aylward, M. and Leacey, D., "Impingement of Dust from Air Jets," Arch. Ind. Hyg. Occup. Med. 4(4): 354-397, 1951.

Davis, 1979: Davis, J. W., "The Use of Sand Substitution to Solve the Free Silica Problem in Foundry Atmospheres," Am. Ind. Hyg. Assoc. J. 40(7):609-618, 1979.

deShazo, 1982: deShazo, R. D., "Current Concepts about the Pathogenesis of Silicosis and Asbestosis," J. Allergy Clin. Immunol. 70(1):41-49, 1982.

Fairhall, 1950: Fairhall, L. T., Couchman, C. E., Ingram, F. R., et al., "Threshold Limit Values," Arch. Ind. Hyg. Occup. Med. 98(2):98-100, 1950.

Finkelstein, 1982: Finkelstein, M., Kusiak, R. and Suranyi, G., "Mortality Among Miners Receiving Workmen's Compensation for Silicosis in Ontario: 1940-1975," J. Occup. Med. 24(9):663-667, 1982.

Goldsmith, 1982: Goldsmith, D. F., Guidotti, T. L. and Johnston, D. R., "Does Occupational Exposure to Silica Cause Lung Cancer?" Am. J. Ind. Med. 3(4):423-40, 1982.

Hatch, 1936: Hatch, T. and Moke, C., "The Mineralogical Composition of Air-Borne Foundry Dust," J. Ind. Hyg. and Toxicol., 18(2):91-97, 1936.

Hickey, 1978: Hickey, J. L. S., Wright, M. D., Warren, J. L. et al., Research Triangle Institute, Abrasive Blasting, Technological Feasibility Assessment and Economic Impact Analysis of the

Proposed Federal Standard, contract no. J-9-F-6-0225, submitted to the Occupational Safety and Health Administration, U. S. Department of Labor, Washington, DC, September, 1978.

ILO, 1976: International Labour Office, Encyclopaedia of Occupational Safety and Health, Vol. II, McGraw-Hill Book Co., New York, 1976.

Irwig, 1978: Irwig, L. M. and Rocks, P., "Lung Function and Respiratory Symptoms in Silicotic and Non-silicotic Gold Miners," Am. Rev. Respir. Dis. 117(3):429-435, 1978.

Jones, 1975: Jones, R. N., Weill, H. and Ziskind, M., "Pulmonary Function in Sandblasters' Silicosis," Bull. Physiopath. Resp. 11(4):589-595, 1975.

Lippmann, 1970: Lippmann, M., "'Respirable' Dust Sampling," Am. Ind. Hyg. Assoc. J. 31(2):138-159, 1970.

Mangia, 1975: Mangia, A., "Determination of α-Quartz in Atmospheric Dust: A Comparison Between Infrared Spectrometry and X-ray Diffraction," Analyt. Chem. 47(6):927-929, 1975.

Morris, 1983: Morris, N., North Carolina Department of Human Resources, Division of Health Services, Occupational Health Section, personal communication, June 6, 1983.

NC, 1938: North Carolina Division of Industrial Hygiene, "Summary of Results Obtained to Date in a Study of the Occupational Disease Hazards Associated with the Quarrying, Crushing and Screening of North Carolina Granites," Raleigh, NC, July, 1938.

Nelson, 1978: Nelson, H. M., Rajhans, G. S., Morton, S. et al., "Silica Flour Exposures in Ontario," Am. Ind. Hyg. Assoc. J. 39(4):261-269, 1978.

NIOSH, 1974: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Criteria for a Recommended Standard-Occupational Exposure to Crystalline Silica, HEW Publication No. (NIOSH) 75-120, 1974.

NIOSH, 1976: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. Engineering Control and Work Practices Manual, HEW Publication No. (NIOSH) 76-179, 1976.

NIOSH, 1976a: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. Recommended Industrial Ventilation Guidelines, HEW Publication No. (NIOSH) 76-172, 1976.

NIOSH, 1977: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, "Quartz in Coal Dust by Infrared Spectroscopy," in NIOSH Manual of Analytical Methods, 2nd ed., Vol I, DHEW (NIOSH) Publication No. 77-157-A, 1977.

NIOSH, 1978: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. National Occupational

Hazard Survey, Volume III, Survey Analysis and Supplemental Tables, HEW Publication No. (NIOSH) 78-114, 1978.

NIOSH, 1978a: U. S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, "An Evaluation of Occupational Health Hazard Control Technology for the Foundry Industry," DHEW (NIOSH) Publication No. 79-114, 1978.

NIOSH, 1980: U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Update of the Literature: Crystalline Silica, no publication number, 1980.

NIOSH, 1981: U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, "Silica Flour: Silicosis," in Current Intelligence Bulletin 36, DHHS (NIOSH) Publication No. 81-137, 1981.

NIOSH, 1981a: U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. Proceedings of the Symposium on Occupational Health Hazard Control Technology in the Foundry and Secondary Non-ferrous Smelting Industries, DHHS (NIOSH) Publication No. 81-114, 1981.

NIOSH, 1983: U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, personal communication with the Proficiency Analytical Testing program office (J. Groff), August 4, 1983.

Ohman, 1978: Ohman, K. H. G., "Prevention of Silica Exposure and Elimination of Silicosis," Am. Ind. Hyg. Assoc. J. 39(11):847-859, 1978.

OSHA, 1981: U. S. Department of Labor, Occupational Safety and Health Administration, General Industry OSHA Safety and Health Standards, Publication No. OSHA 2206 Revised, June, 1981.

OSHA, 1982: U. S. Department of Labor, Occupational Safety and Health Administration, Industrial Hygiene Manual, Chapter IX, as amended, June 14, 1982.

OSHA, 1983: U. S. Department of Labor, Occupational Safety and Health Administration, Advance Notice of Proposed Rulemaking: Health Standards, Federal Register, Vol. 48, p. 7473, February 22, 1983.

Oudiz, 1983: Oudiz, J., Brown, J. W., Ayer, H. E., et al., "A Report on Silica Exposure Levels in United States Foundries," Am. Ind. Hyg. Assoc. J. 44(5):374-376, 1983.

Parkes, 1982: Parkes, R. N. R., "Diseases Due to Free Silica," in Occupational Lung Disorders, by W. R. Parkes (London, Butterworth and Co., 1982).

Peterson, 1976: Peterson, J. E., "Principals for Controlling the Occupational Environment," in The Industrial Environment - Its Evaluation & Control," U. S. Department of Health, Education and

Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, 1973.

Rice, 1983: Rice, C., Harris, R. L. Jr., Checkoway, H., et al., "Exposure Reconstruction and Case-Control Study of Silicosis in North Carolina," paper #298 presented at the American Industrial Hygiene Conference, Philadelphia, PA, May 26, 1983.

Roach, 1967: Roach, S. A., Baier, E. J., Ayer, H. E. et al., "Testing Compliance with Threshold Limit Values for Respirable Dust," Am. Ind. Hyg. Assoc. J. 28(6):543-553, 1967.

Rodgers, 1983: Rodgers, S. J. and Jayaraman, N., "Control of Respirable Coal Dust in Conventional Coal Mining Operations," paper #39 presented at the American Industrial Hygiene Conference, Philadelphia, PA, May 23, 1983.

Ryer, 1978: Ryer, F. H., "Air Pollution Exposures to Five Target Health Hazards," Am. Ind. Hyg. Assoc. J. 39(11):928-931, 1978.

Samimi, 1975: Samimi, B., Nelson, A., Weill, H. et al., "The Efficiency of Protective Hoods Used by Sandblasters to Reduce Silica Dust Exposure," Am. Ind. Hyg. Assoc. J. 36(2):140-148, 1975.

Samimi, 1976: Samimi, B., Weill, H., and Ziskind, M., "Respirable Silica Dust Exposure of Sandblasters and Associated Workers in Steel Fabrication Yards," Arch. Environ. Hlth. 29(2):61-66, 1974.

Sanderson, 1983: Sanderson, W. T., Abrons, H. Petersen, M. et al., "Results of Industrial Hygiene Surveys of Portland Cement Plants," paper #34 presented at American Industrial Hygiene Conference, Philadelphia, PA, May 23, 1983.

Seaton, 1975: Seaton, A., "Silicosis," in Occupational Lung Diseases, W. K. C. Morgan and A. Seaton eds. (Philadelphia, W. B. Saunders, 1975).

Shaw, 1981: Shaw, F. M., "Some Design Criteria for Reducing Dust During the Cleaning and Finishing of Iron Castings," in Proceedings of the Symposium on Occupational Health Hazard Technology in the Foundry and Secondary Non-ferrous Smelting Industries, U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-114, pp. 14-38, August 1981.

Shaw, 1981a: Shaw, F. M., "Some Design Criteria for Reducing Dust When Handling Clay Bonded Sand," in Proceedings of the Symposium on Occupational Health Hazard Technology in the Foundry and Secondary Non-ferrous Smelting Industries, U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-114, pp. 168-187, August 1981.

Spencer, 1977: Spencer, H., Pathology of the Lung. (Philadelphia, W. B. Saunders Co., 1977).

Stenback, 1979: Stenback, F. and Rowland, J., "Experimental Respiratory Carcinogenesis in Hamsters: Environmental, Physicochemical and Biological Aspects," Oncology 36(2):63-71, 1979.

Sutton, 1968: Sutton, G. W. and Reno, S. J., "Respirable Mass Concentration Equivalent to Impinger Count Data, Barre, VT Granite Sheds," Presented at 1968 Annual Meeting, American Industrial Hygiene Association, St. Louis, MO, 1968.

SW, 1983: Office of the Labor Attache, Swedish Embassy, Washington, DC, Personal communication, August 8, 1983.

Sweet, 1978: Sweet, D. V., Crouse, W. E., and Crable, J. V., "Chemical and Statistical Studies of Contaminants in Urban Lungs," Am. Ind. Hyg. Assoc. J. 39(7):515-526, 1978.

Talvitie, 1964: Talvitie, N. A., "Determination of Free Silica - Gravimetric and Spectrophotometric Procedures Applicable to Air-borne and Settled Dust," Am. Ind. Hyg. Assn. J., 25(3): 169-178, 1964.

Tepordei, 1982: Tepordei, V. V., "Sand and Gravel," in Minerals Yearbook, 1981, Vol. II, U. S. Department of the Interior, Bureau of Mines, 1982.

Theriault, 1974: Theriault, G. P., Burgess, W. A. DiBerardinis, L. J. et al., "Dust Exposure in the Vermont Granite Sheds," Arch. Environ. Hlth. 28(1):12-17, 1974.

Theriault, 1974a: Theriault, G. P., Peters, J. M. and Fine, L. J., "Pulmonary Function in Granite Shed Workers in Vermont" Arch. Environ. Hlth., 28(1):18-22, 1974.

Theriault, 1974b: Theriault, G. P., Peters, J. M. and Johnson, W. M., "Pulmonary Function and Roentgenographic Changes in Granite Dust Exposure," Arch. Environ. Hlth., 28(1):23-27, 1974.

Trice, 1938: Trice, M F. and Easom, H. F., "Report of a Study of the Foundry Industry in North Carolina," Division of Industrial Hygiene, North Carolina Board of Health, Raleigh, NC, 1938.

Tubich, 1981: Tubich, G. E., "The Foundry--Its Real Potential Health Hazards," in Proceedings of the Symposium on Occupational Health Hazard Technology in the Foundry and Secondary Non-ferrous Smelting Industries, U. S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-114, 1981.

USDOC, 1981: U. S. Department of Commerce, Bureau of the Census, 1977 Census of Manufactures, Vol. II, 1981.

USDOC, 1981a: U. S. Department of Commerce, Bureau of the Census, 1977 Census of Mineral Industries, 1981.

USDOL, 1980: U. S. Department of Labor, Office of the Assistant Secretary for Policy, Evaluation and Research, An Interim Report to Congress on Occupational Diseases, Washington, DC, 1980.

USDOL, 1982: U. S. Department of Labor, Mine Safety and Health Administration, Regulations and Standards Applicable to Metal and Nonmetal Mining and Milling Operations and to Coal Mining. 30 CFR 55, 56, 57, 70 and 71, Washington, DC, 1982.

Westerholm, 1980: Westerholm, P., "Silicosis: Observations on a Case Register," Scan. J. Work Environ. Health 6(supp. 2):1-86, 1980.

485

Ziskind, 1976: Ziskind, M , Weill, H. Anderson, A. E. et al., "Silicosis in Shipyard Sandblasters," Environ. Res. 11(2):237-243, 1976.

Ziskind, 1976a: Ziskind, M., Jones, R. N., and Weill, H., "State of the Art: Silicosis," Am. Rev. Resp. Dis. 113(5):643-665, 1976.

Glossary

Abrasive blasting: a process in which a stream of high velocity particles is directed through a nozzle or channel against a surface in order to finish or clean it, or to relieve internal stress. The high velocity is achieved with centrifugal force or air pressure (Hickey, 1978).

ACGIH: the American Conference of Governmental Industrial Hygienists, a professional organization which establishes voluntary occupational exposure standards (see Threshold Limit Values) and performs other activities related to occupational health (ACGIH, 1982).

Count method: a method used in the past to measure the concentration of silica-containing dust particles in air as the number of dust particles per cubic foot of air (mppcf), as a basis for establishing exposure limits.

Cristobalite: see Silica.

Crystalline silica: see Silica.

Free silica: see Silica.

Mass method: a method used since the 1960's to measure the concentration of silica in air as weight of silica-containing dust per volume of air (milligrams of dust per cubic meter of air), as a basis for establishing exposure limits.

Microgram: one millionth of a gram.

Milligram: one thousandth of a gram.

MSHA: the Mine Safety and Health Administration, an agency of the U. S. Department of Labor, with authority to establish and enforce health standards in mining industries (USDOL, 1982).

mppcf: see Count method.

NIOSH: the National Institute for Occupational Safety and Health, an agency of the U. S. Department of Health and Human Services, empowered by Public Law 91-596 to perform research on and recommend standards related to occupational health and safety (NIOSH, 1974).

OSHA: the Occupational Safety and Health Administration, an agency of the U.S. Department of Labor, empowered by Public Law 91-596 to establish and enforce occupational safety and health standards in industry (OSHA, 1981).

PEL: Permissible Exposure Limit, the term used by OSHA in mandatory standards to describe the upper allowable limit of worker exposure to a substance in air. PELs of chemicals are usually expressed in terms of parts of substance per million parts of air (ppm) or weight of substance per volume of air (milligrams or micrograms of substance per cubic meter of air). Many current PELs were adopted in 1970 from then current TLVs (see TLV) (OSHA, 1981).

Quartz: see Silica.

Respirable silica: that portion of dust in air made up of silica particles small enough to reach the alveolar regions of the lung when inhaled.

Sand blasting: the use of sand propelled by compressed air to perform abrasive blasting (see Abrasive blasting).

Silica: Silicon dioxide (SiO_2). Silica may be in the form of crystalline (or free) silica, of which quartz, cristobalite, and tridymite are three polymorphs of major health significance, or as non-crystalline (or amorphus) silica, considered to be less hazardous. Cristobalite and tridymite are formed when silica is subjected to high temperatures; these forms are considered more hazardous than quartz and have lower exposure limits than quartz.

TLV: Threshold Limit Values, voluntary limits established by the American Conference of Governmental Industrial Hygienists for occupational exposure to chemical contaminants in air. TLVs describe the airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect (ACGIH, 1982).

Tridymite: see Silica.

COMPLIANCE WITH THE OSHA COTTON DUST RULE

The Role of Productivity Improving Technology

Final Report

For Office of Technology Assessment
Contract No. 233-7050.0

Dr. Ruth Ruttenberg
Ruttenberg, Friedman, Kilgallon & Associates, Inc.
1211 Connecticut Avenue, N. W.
Washington, D. C. 20036

March 1983

COMPLIANCE WITH THE OSHA COTTON DUST RULE
The Role of Productivity Improving Technology

For The Office of Technology Assessment

Dr. Ruth Ruttenberg
Ruttenberg, Friedman, Kilgallon & Associates, Inc.
March 1983

EXECUTIVE SUMMARY

The U. S. textile industry is already in substantial compliance with the federal regulations for control of cotton dust by 1984. Since the federal government promulgated its first cotton dust regulation in 1968, and especially since promulgation and court support for the current 1978 regulation of the Occupational Safety and Health Administration, there has been a technological revolution in the manufacturing process for cotton textiles. It is impossible to make any quantitative determination of the exact cause and effect relationship between regulating cotton dust and modernization of textile mills. It is clear, however, that a relationship exists. While modernization of the textile industry would have occurred, many mills would not have modernized as quickly, and few would have incorporated as much control technology as they did without the OSHA rule. OSHA compliance has been less expensive and more timely because of the link between modernization and the technology-forcing of the rule.

Significant in a post-regulatory review is the fact that control technology and not add-ons has been the dominant mode of compliance. This means that capital investment has been able to achieve productivity and quality improvements simultaneously with dust control. Expenditures have been for "defensive" (compliance) purposes but they have also concurrently achieved operational improvements.

The post-regulatory view of controlling cotton dust is a very different one from the prepromulgation debate.

The studies performed before the promulgation of the regulation

projected that for compliance with OSHA's cotton dust regulation, industry would primarily rely on retrofits, add-ons and enclosures, to better ventilate, sweep and vacuum air-borne dust. While some of these techniques for compliance are being used and are necessary for compliance, designed-in engineering controls, which control for dust at its source have become an integral part of plant modernization schemes. Cotton textile manufacturing is more technologically consolidated than ever before, fully eliminating some of the processes which had previously been responsible for a substantial amount of worker exposure. New machine systems operate faster and with fewer breakdowns and errors. Not only are the processes less dusty, but many are less noisy, and humidity and temperature are better controlled. Energy efficiency, space efficiency and materials efficiency have been achieved and product quality has been improved as well. The U.S. textile industry has been registering the highest annual average productivity growth of any industrial grouping in the manufacturing sector.

The prepromulgation debate asserted that the capital costs of compliance (converted to 1982 dollars) would range from $875 million to nearly $2 billion. An extensive 1983 OSHA study has concluded that the capital costs really will run $245 million — the difference in large part being because control technology and not add-ons have dominated corporate strategies for compliance.

It would be hard to claim that OSHA's cotton dust regulation has in any way seriously damaged industry profitability. Some would say that OSHA has actually enhanced and encouraged profitable activities. Many corporate executives and plant managers, while still objecting to various aspects of the cotton dust rule, admit that in many of the plants which they have modernized (and they must modernize to survive), the existence of the OSHA rule caused them to make a more timely decision, and in many cases, a more systematic decision. The necessity for making changes in plant machinery for OSHA compliance created an opportunity for engineers to make other equipment improvements simultaneously. Similarly the process of changing plant machinery to improve profitability made it easier to make changes that would improve dust control. In many cases, the timing of modernization and of compliance efforts fit hand-in-glove.

In other cases, the process of modernization has brought plants into compliance almost automatically — at least for some parts of the manufacturing process. New sophisticated machinery has lower dust tolerance and, therefore, requires a cleaner work environment. Downtime on new faster machines is more expensive, so automatic traveling cleaners have become important for the healthy maintenance of capital as well as labor. The chute-fed card system is more productive when enclosed. That enclosure also eliminates employee exposure to cotton dust. In many of these cases, concern for either OSHA compliance or for productivity could have contributed to an investment decision. But the actual development of innovative techniques was the result of incentives to compete, modernize and survive with profit. The cotton dust rule accelerated the investment, but most of the actual technological improvements had already been developed. OSHA's cotton dust regulation promoted, to a large extent, the adoption of new technology. The regulation, however, was not as important a factor behind the R&D which resulted in the new techniques.

Specific findings of this report include:

- Modernized opening and picking is faster, less dusty and leads to a better blend of cloth.
- New carding techniques eliminate doffing, racking and manual transport as well as improving speeds and yarn quality. There is

a reduction in floor space requirements, in labor turnover, in broken threads, and in dust exposure.

- New spinning technology can eliminate roving and drawing as well as reduce dust exposure.
- Shuttleless looms substantially increase productivity, allow for greater versatility in production, and alleviate noise, temperature and humidity problems as well as (non-oil mist) dust levels.
- Nearly all large and medium size companies have invested heavily in new capital-intensive technology. The industry has been making major decisions as companies shut down old, inefficient plants, rebuild some existing plants and construct new ones.
- The U.S. textile machinery manufacturing industry is losing ground in the $1.6 billion U.S. market and the $7.1 billion world market. Most new technology of complete machines, especially in spinning, weaving, winding and knitting is coming from West Germany, Switzerland, France, Italy, Japan and Great Britain.
- The U.S. textile machinery manufacturing industry has a healthy parts and accessories market. It also is competing well in rebuilt and converted equipment.

TABLE OF CONTENTS

PAGE

EXECUTIVE SUMMARY i

INTRODUCTION 1

Chapter I: Cotton Processing and the Dust Hazards Involved 2

Opening, Cleaning, Picking.................................... 4

Carding.. 11

Drawing.. 15

Roving... 17

Spinning and Winding, Twisting, Spooling, Warping............. 18

Weaving.. 27

Chapter II Regulatory History 29

Evidence of Respiratory Disease............................... 29

The Current Standard... 33

Chapter III Relationship Between OSHA Regulations and the Development of New Technologies 41

Technology Forcing and OSHA.................................. 43

Technological Change in the Textile Industry Level of Compliance After Two Years.............................. 50

Chapter IV Innovative Technologies Employed in the Textile Industry 62

Opening and Picking.. 62

Carding.. 63

Spinning... 68

Weaving.. 69

Rebuilt Cards.. 75

Conversion From Shuttle to Shuttleless Looms.................. 75

Corporate Decisions on Modernization.......................... 78

The U.S. Textile Machinery Industry Is Moving More Slowly Than the Textile Industry............................ 85

The Textile Industry in Transition............................ 88

PAGE

Chapter V Productivity and Other Improvements in the Textile Industry 92

Energy Savings.. 93

Improvement in Product Quality.................................... 94

Increases in Recycling and Capture of Resalable Byproducts........ 96

Reduction in Needed Floor Space................................... 97

Reduced Noise and Vibration....................................... 97

Reduction in Turnover Costs....................................... 98

Chapter VI Summary of Impacts of Cotton Dust Regulation and of the New Control Technologies 99

Economic Impacts.. 99

Has There Been A Shift to Synthetics?............................ 100

Overall Impacts Most Dependent on Methods of Compliance and Timing of Investments......................... 101

Footnote References 104

Appendix:

GLOSSARY 113

LIST OF TABLES

PAGE

Table 1 Gross Average Cotton Dust Levels Reported by Various Investigators 7

Table 2 Prevalence of Byssinosis 34

Table 3 Prevalence of Byssinosis Compared To Known Dust Exposures 35

Table 4 Comparisons of Estimates for Capital Cost of Compliance, OSHA Cotton Dust Standard 37

Table 5 Litigation 39

Table 6 Percentage of Companies Claiming Compliance with the PEL in 1981 51

Table 7 Major Manufacturing Categories Ranked According to Productivity Growth Rates, 1948-79 57

Table 8 Textile Machinery Sales by U.S. Companies 87

Table 9 U.S. Domestic Cotton Consumption, Million Bales, 1976-1983 102

LIST OF FIGURES

		PAGE
Figure 1	Basic Steps in Manufacturing Cotton Fabrics	3
Figure 2	Flow Diagram - Raw Cotton Processing	5
Figure 3	Layout of Opening of Machinery	9
Figure 4	Cross Section Through A Card Feed Works Showing How The Feed Plate, Feed Roll, Licker-in and Mote Knives Work Together	13
Figure 5	Card Cleaning System	16
Figure 6	Cross Section Through The Roving Frame	19
Figure 7	Cross Section Through Rug Spinning Frame Equipped With Open Creed and Double Apron Drafting System	20
Figure 8	Cross Section of Open-End Spinning Machine	24
Figure 9	Index of Control Techniques and Processing Variables	53
Figure 10	Typical Bale-O-Matic Layout For Automated Cotton-Synthetic Opening Room Blending	64
Figure 11	Typical Bale-O-Matic Tuft-O-Matic Opening Room (30 Bale Blend); Cotton/Synthetic Intimate Blending Line; Cotton & Synthetic Waste Automatically Fed	65
Figure 12	Photograph of Bale-O-Matic, American Materials Handling	66
Figure 13	Hopper Feed Table - Bale-O-Matic	67
Figure 14	The Supercard in the Production System	70
Figure 15	Photograph of Aerofil Loom System, Leesona Corporation	71
Figure 16	Photograph of Jettis Loom, Omintex	72
Figure 17	Electronic Levelling System	76

INTRODUCTION

A technological revolution is occurring in the textile industry. Some of this technology, while improving productivity and product quality, also controls worker exposure to cotton dust. This paper explores the process of technological change in the textile industry, in an effort to determine what relationship, if any, exists between the promulgation of the OSHA cotton dust regulation and the emergence of new textile technology.

Antiquated textile machinery produced an extremely dusty work environment. The lungs of workers as well as the gears of machines and yarn of fabrics became clogged with cotton dust. As innovative technologies have been used in the industry, worker exposure has been reduced, machines operate better and longer, and yarn and cloth are both stronger and of higher quality. It is just possible that for many of the companies which have modernized, that a "win-win" situation has emerged, i.e., that workers "win" with reduced exposure to hazardous dust and management "wins" with improved productivity. Investments for modernization have been costly, but have not harmed worker health, consumer satisfaction or company profitability. In fact, all three, having weathered a rough period of change in the textile industry, are in a healthier condition than before.

Chapter I

Cotton Processing and the Dust Hazards Involved

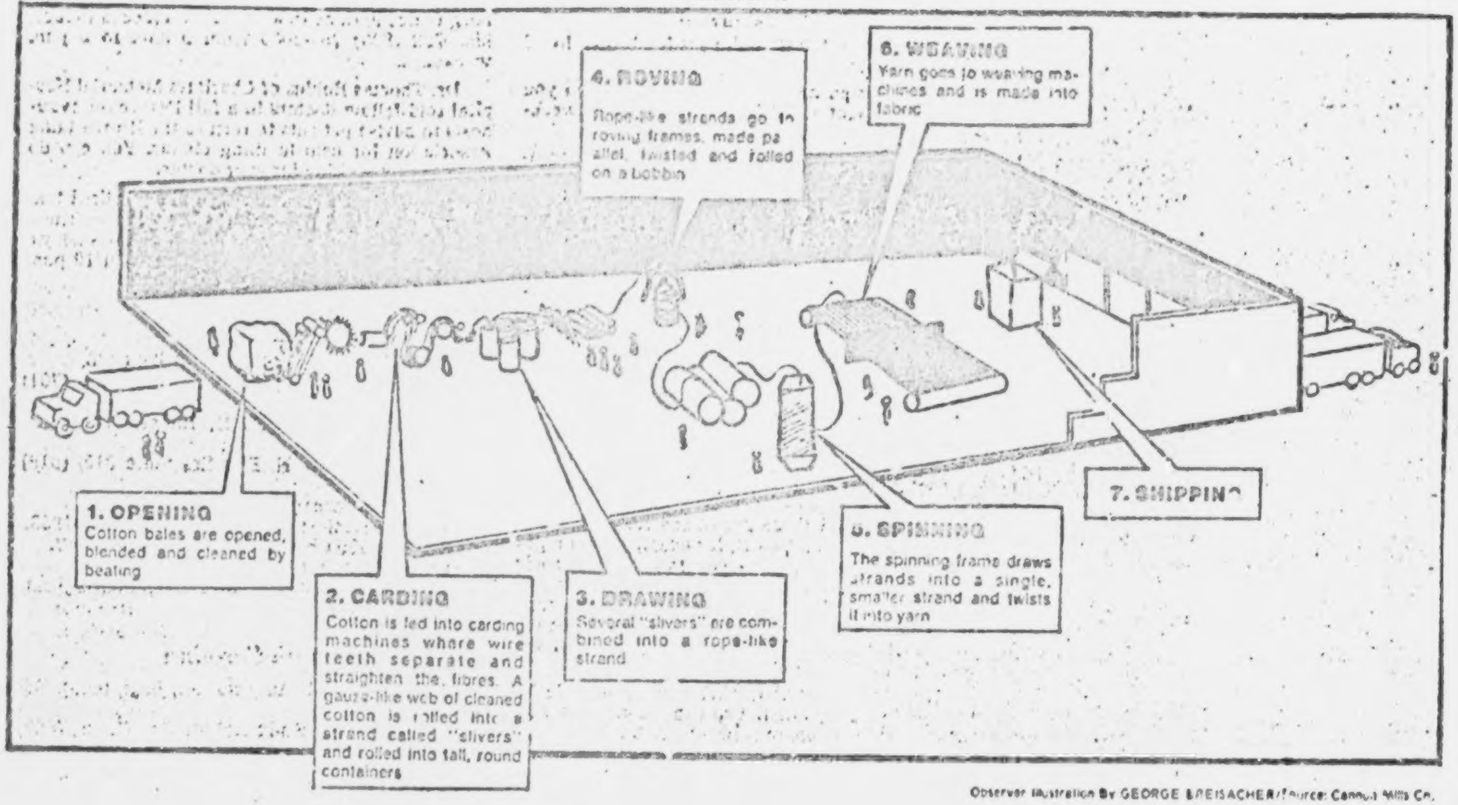
Cotton arrives at the mill for processing in tightly packaged bales, of approximately 500 pounds, that contain leaf trash and other foreign matter mixed with the raw cotton. Generally, the various steps in the processing of the raw cotton to cloth are designed to open the bales, clean out the trash, open the cotton tufts into fibers, blend the fibers with other materials such as synthetics, draw out the fibers, spin them into yarn, spool the yard, and weave it into cloth. (See Figure 1.) Cotton dust levels and the composition of dust fibers vary at each processing stage.

The "traditional" American method of accomplishing this transformation has involved a large amount of manual feeding and handling between each process. Machinery was exposed and conveyor belts were open. The late 1960s, however, the technology was changing toward (1) a more continuous processing method characterized by automatic feeding and transfers of materials from one stage to another, (2) higher speed operations, and (3) the combination of several traditional steps into one machine. The reasons for the technological developments were originally economic, labor saving ones, according to a 1974 study by the American Textile Manufacturer's Institute.[1] By their very nature, however, the newer types of machinery were also far more effective in controlling dust, or at least far more amenable to engineered controls for dust, than were the more disjointed, open, and labor-intensive methods. And the need to control the dust that was created by the subsequent regulation undoubtedly gave additional impetus to these types of developments.

The following section will describe in some detail both the

Reproduced from best available copy.

FIGURE 1


1. OPENING
Cotton bales are opened, blended and cleaned by beating
2. CARDING
Cotton is fed into carding machines where wire teeth separate and straighten the fibres. A gauze-like web of cleaned cotton is rolled into a strand called "slivers" and rolled into tall, round containers
3. DRAWING
Several "slivers" are combined into a rope-like strand
4. ROVING
Rope-like strands go to roving frames, made parallel, twisted and rolled on a bobbin
5. SPINNING
The spinning frame draws strands into a single, smaller strand and twists it into yarn
6. WEAVING
Yarn goes to weaving machines and is made into fabric
7. SHIPPING

Observer Illustration By GEORGE BREISACHER/Source: Cannon Mills Co.

Basic Steps In Manufacturing Cotton Fabric (Drawing Not To Scale)

Source: Charlotte Observer, February 3-10, 1980.

"traditional" methods of processing raw cotton to cloth, as well as some of the changes in those methods that began to appear in the 1970s -- all in relation to the dust exposure hazard at each point in the processing. The stages discussed are: (1) opening, with its cleaning, blending and picking, (2) carding, (3) drawing, (4) roving, (5) spinning with its winding, spooling, twisting and warping, (6) weaving. (See Figure 2.) This paper does not discuss ginning, cottonseed processing, etc. (Throughout this paper, refer to glossary for definitions of technical terms.)

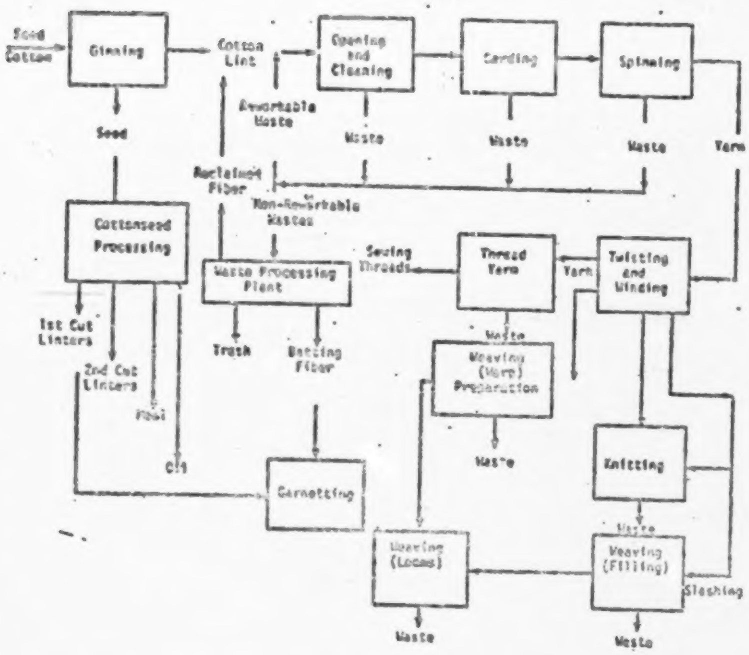
Opening, Cleaning, Picking

The beginning of cotton processing included "opening," "cleaning," "blending," and "picking." It began with a tightly packed bale of cotton and ended with a "lap," which is a partially cleaned, flat, even sheet in roll from which had to be hand-fed to the next stage (carding).

In traditional systems, layers of cotton were manually removed from the bales and fed into hoppers. The cotton was tumbled in the hoppers to break it into small tufts and to mix the cotton from the various bales. The material was then transported either by belt conveyor or through pneumatic ductwork to pre-openers or cleaners which reduced the tuft size and removed some of the non-lint waste material. Some of these machines have rotating metal finger beaters and grid bars through which trash is removed, while others have a series of rotating cylinders covered with a metallic sawtooth clothing for separation of cotton tufts into a very small size. If the cotton is to be blended with other materials such as synthetic fibers, additional hoppers similar to opening hoppers are used. Dust emissions in opening tend to be generated by: opening the bales, handling of the cotton from bale to hopper, tumbling in the hopper,

FIGURE 2

FLOW DIAGRAM - RAW COTTON PROCESSING


Seed Cotton
Ginning
Cotton Lint
Opening and Cleaning
Carding
Spinning
Seed
Reworkable Waste
Waste
Waste
Waste
Yarn
Reclaimed Fiber
Non-Reworkable Wastes
Cottonseed Processing
Waste Processing Plant
Sewing Threads
Thread Yarn
Yarn
Twisting and Winding
1st Cut Linters
2nd Cut Linters
Meal
Oil
Trash
Batting Fiber
Waste
Weaving (Warp) Preparation
Waste
Knitting
Garnetting
Waste
Weaving (Looms)
Weaving (Filling)
Slashing
Waste
Waste

Reproduced from best available copy.

Source: Enviro Control, Inc., for NIOSH, "Control Technology Assessment of Raw Cotton Processing Operations," June 15, 1980.

delivery from the opener to conveyor, and the manual removal of waste from hopper, feeder rolls and under machine.[2] (See Figure 3 for layout of opening machinery.)

Picking equipment continues to open the fiber, continues to remove trash and short fibers, to mix the processed cotton, and to form a uniform lap.

The greatest cotton dust hazards come in early preparation processes — opening, cleaning, blending, picking, and also carding. According to the Research Triangle Institute (RTI) study done for OSHA in 1976 (to measure the economic and technological feasibility of the proposed standard) "The most common sources of cotton dust contamination in opening/cleaning systems are manual feeding of blending feeders, the blending hoppers themselves, the exposed feed table or conveyor, pressure points in openers, and the condenser. Although the machines are fairly well enclosed and are furnished with a type of exhaust system which removes larger diameter particles, respirable concentrations of dust in these areas may be high. Samples taken with the vertical elutriator (V.E.) have indicated uncontrolled concentrations on the order of 1. mg/m^3 (1600 ug/m^3, i.e., micrograms per cubic meter)." (See Table 1.) RTI identifies dust sources in typical picking equipment to be generated from internal mechanical action, inadequate filtration devices located on the pressure side of the condenser fan, and manual doffing and handling of the picker lap.[3] Measured dust concentrations in the picking area shown in Table 1 ranged from 0.7 to 1.7 mg/m^3 (700 to 1700 ug/m^3).

To the extent that manual handling of bales is minimized, hopper feeders are enclosed, openers are well sealed, and enclosed pneumatic or suction ducts are used to transport the cotton rather than open conveyor

Table 1

Gross Average Cotton Dust Levels Reported by Various Investigators

Operation	Investigator		Dust (mg/cu m)	Dust Excluding Lint (mg/cu m)	
				Fixed Sampler/	Personal Sampler
Ginning	El Batawi et al	[109]	15		
	Gilson et al	[31]		6-57 (RS)	
	Khogali	[111]		0.6 (RS)	
	Barnes & Simpson	[112]	20		
Opening	Hammad & Corn	[130]	7.1	3.0 (RS)	
	Hatcher & Lyons	[130]			3.1
	Merchant	[131]		1.6 (L)	
	Anglin	[134]		0.3 (L)	
	Silverman	[135]	17.2		
Picking	Lynch	[124]	6.6	0.7 (L)	2.5
	Hatcher & Lyons	[133]			1.3
	Merchant	[131]		1.7 (L)	
	Hammad & Corn	[130]	1.4	1.1 (RS)	
	Silverman	[135]	3.8		
Carding	Lynch	[124]	5.0	0.3 (L)	3.0
	Hammad & Corn	[130]	1.2	0.6 (RS)	
	Wood & Roach	[11]	1.6	1.0 (RS)	
	Merchant	[131]		1.8 (L)	
	Hatcher & Lyons	[133]			1.9
	Anglin	[134]		0.4 (L)	
	Silverman	[135]	4.1		
Drawing	Hammad & Corn	[130]	3.2	0.7 (RS)	
	Merchant	[131]		0.8 (L)	
	Anglin	[134]		0.4 (L)	
	Lynch	[124]	3		2.1
	Silverman	[135]	3.5		
Roving	Merchant	[131]		0.5 (L)	
	Silverman	[135]	4.0		
Spinning	Lynch	[124]	4.0	0.2 (L)	0.7
	Merchant	[131]		0.3 (L)	
	Hammad & Corn	[130]	1.8	0.3 (RS)	
	Silverman	[135]	1.5		

Table 1 (Continued)

Gross Average Cotton Dust Levels Reported by Various Investigators

Operation	Investigator		Dust (mg/cu m)	Dust Excluding Lint (mg/cu m)	
				Fixed Sampler	Personal Sampler
Wind & Twist	Lynch	[124]	14.3	0.3 (L)	1.2
	Merchant	[131]		0.3 (L)	
	Silverman	[135]	0.7		
Weaving	Lynch	[124]	1.4	0.4 (L)	0.8
	Merchant	[131]		1.1 (L)	
	Silverman	[135]	3.1		

*This table lists crude average dust levels. It is not complete and it makes no attempt to differentiate either between levels measured with or without controls, or between the grades of cotton being processed. It also does not take into account the variability of the individual dust samples as reported by the different investigators.

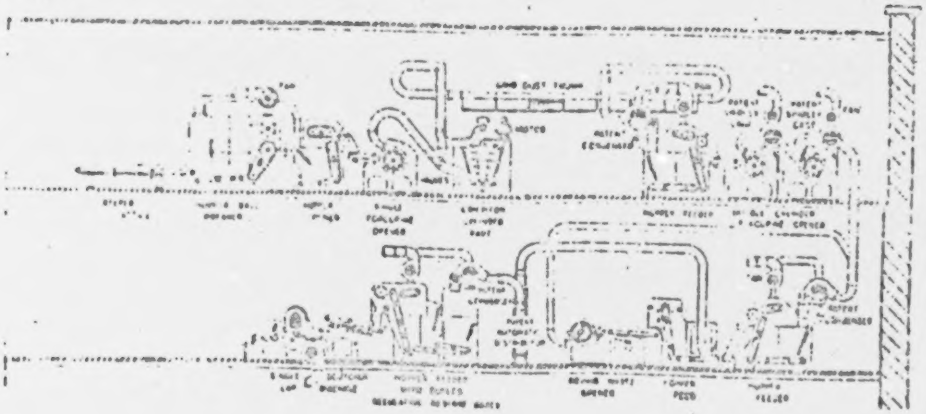
Note: (L) Refers to vertical elutriator of Lumsden and Lynch. [124]
(RS) Refers to horizontal elutriator of Roach and Schilling. [85]
Measurement includes fine and medium size particles.

Source: NIOSH, Occupational Exposure to Cotton Dust, 1974.

FIGURE 3

LAYOUT OF OPENING MACHINERY

Reproduced from best available copy.



Source: A.J. Hall, The Standard Handbook of Textiles, (Chemical Publishing Co., Inc.: New York) 1966.

belts, exposure in the opening/cleaning phase is reduced. The RTI study mentions a modern Karousel^tm type opener in which tufts of cotton are pulled from the bottom of bales and transferred via a pneumatic handling system to subsequent cleaning equipment as being effective in minimizing manual handling and thus exposure to cotton dust. The 1974 ATMI study indicates that by that year, six to eight companies had begun to offer automatic feeding systems. Nearly a decade later, the numbers have multiplied many times over. The RTI study noted in 1976 a trend towards eliminating the picker and the lap. "Pre-opening is required, but the final opening and cleaning action, rather than forming a lap, feeds tufts of fiber pneumatically to the card feed via a chute. Hence, the manual handling of the lap from the picker to the card is eliminated." No specific reductions in dust levels were cited.

As opposed to the above cited methods of fully enclosing machinery and minimizing handling through automatic transfers from process to process, the RTI study noted that the "current [1976] approach toward capturing dust generated in the opening and picking operations is to utilize exhaust hoods on the open hoppers, feed tables and other conveyors."[4] This replaced the filtration devices on the specific machines and introduced output from fans into filter systems. The dust reduction depended on the number of filtering stages used — one, two or three. Using this method, the air volume requirements to reduce dust levels from as high as 17.2 to 1.0 to 0.5 mg/m^3 (1720 to 1000 to 500 ug/m^3) (see Table 1) in the opening and picking operations ranged up to 3000 cubic feet per minute. RTI was focusing on add-ons for antiquated equipment rather than technology available through modernization.

Just three years later, Enviro Control, Inc., in a report on control technology for NIOSH,[5] found greatly reduced dust levels through the use of automatic feeding and pneumatic transport from opening hoppers, as well as from local exhaust ventilation of opening hoppers and the waste grinder. Sample data from 1979 found mean total dust levels of 397 ug/m^3. This contrasted with a mean dust level of 628 ug/m^3 before the control technology system was installed. Moving from add-ons to a combination of add-ons and improvements in control technology led to very substantial improvements. Automatic feeding using Bale-O-Matic (see Chapter IV), coupled with a time cycle waste extractor and air filtration system led in

1979 to a mean dust level of only 106 ug/m^3 V.E.[6]

Other sources of dust released in the opening/cleaning process, according to ATMI, are the removal and manual handling of waste from hoppers and cleaners and machine cleaning. The 1970 practice, as noted by the SRRL article, was to stop the opening, cleaning and picker lines once per shift to remove waste from under the machines and to blow down the walls and ceiling. "Quite a bit of dust and lint is agitated into the air during this cleaning."[7] Newer, faster and more automated equipment changes this practice considerably.

According to North Carolina OSHA, effective control of cotton dust has been achieved in opening and picking in the following ways:[8]

> Bale opening is still a manual process but exposures can be controlled by good general dilution ventilation. Cotton opening is now mechanically or pneumatically handled...This area is now cleaner and requires less manhours to accomplish the older, dustier method of manual cotton opening.
>
> ...Picking is eliminated in most textile operations with the use of "chute" fed carding machines ... Local exhaust ventilation is available and used when necessary to control dust from this process.

(For more detail on innovations in opening and picking, see Chapter IV.)

Carding

Carding is the next stage in the processing. It is generally agreed that carding is the major point of dust generation in the yarn manufacturing process.[9] Traditionally, among card room workers, 20 to 30 percent develop acute byssinosis within a year or less of exposure. In addition, workers who have severe reactions to dust often leave the textile mill environment, thus creating a "survivor" population which is less susceptible.[10]

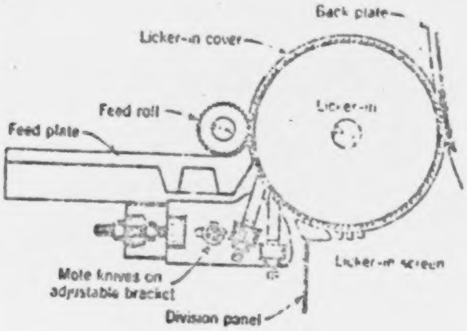
The purpose of carding is to further separate the fibers from the bits of leaf, trash and short fibers, to straighten or parallel the cotton fibers and to form a soft, untwisted ropelike material called sliver. (See Figure 4 for diagram of card feed works.)

> Fibers are brought in over a feed plate to a feed roll and the licker-in. The licker-in is a cylinder covered with wire teeth which rotates rapidly over the lap of cotton held by the feed roll, gradually opening the tufts of cotton in the lap. As the tufts are opened, dirt and trash fall out. Further short fiber and foreign matter are removed by sharp-edged bars close to the licker-in surface, the mote knives. The cotton on the licker-in is taken off by the card cylinder.
>
> Carding action takes place when two wire clothed surfaces are brought together with the teeth inclined in opposite directions, and the relative motions are such that the surfaces pass each other, point against point. Above the card cylinder is a series of many narrow, cast iron flats, each covered with card clothing. The flats move very slowly only centimeters per minute so that compared to the rapidly moving cylinder they are standing still. The carding action to open and straighten the cotton fibers is therefore very vigorous compared to earlier operations.
>
> The fibers are taken from the card cylinder by the doffer, a small cylinder made and clothed like the main cylinder. A fine film of fiber called the card web comes from the doffer and is drawn forward to the center of the front of the card through a tapered opening called the doffer trumpet. The small opening in the front part of the trumpet condenses the 100-cm web to a round sliver about 2.5 cm in diameter. The sliver is coiled into tall cans for further processing.[11]

Air currents are generated within the card by rotation of the licker-in and cylinder. Fine dust particles are discharged at the pressure release points in the housings of the licker-in and cylinder. Some dust is also released at the web take-off from the doffer and during cleaning of the cards.[12] The SRRL study on cotton dust, also quoted in the NIOSH criteria study, indicated that "dust and fly — broken and short fibers — are liberated at the feed roll, the base of the back plate, between the top of the back plate and the flats, between the flats, at the

FIGURE 4

CROSS SECTION THROUGH A CARD FEED WORKS SHOWING HOW THE FEED PLATE, FEED ROLL, LICKER-IN AND MOTE KNIVES WORK TOGETHER


Back plate
Licker-in cover
Licker-in
Feed roll
Feed plate
Mote knives on adjustable bracket
Licker-in screen
Division panel

Source: The American Cotton Handbook, Volume I.

stripper door, at the base of the front bottom plate, and at the doffer cylinder and comb.[13] The RTI study suggested that the bulk of the dust was generated from two places, the licker-in and the flats comb. Concentrations as high as 1.8 mg/m^3 (1800 ug/m^3), V.E. have been measured. (See Table 1.)[14]

According to NIOSH, a major source of dust in the carding process has been the "stripping and grinding" of card clothing. Strippers and grinders invariably had the most severe byssinosis problem of any of the cardroom occupations.[15] As cotton is processed by the card, fibers gradually collect between the wires of "fillet" -- fabric and wire — card clothing. If too much cotton collects in the clothing wire, poor carding results. Consequently, it is necessary periodically to remove the accumulated waste. This is called stripping.[16] This was traditionally done by hand from one to three times during every shift. In "recent years" (1960s and early 1970s) hand stripping was largely replaced by vacuum stripping. This substantially reduced the dust and lint in the card rooms.

Use of metallic clothing for the cylinder and doffer, instead of the traditional fabric and wire (fillet) clothing, reduces the need for stripping to once per 120-144 hour week. Metallic clothing, however, which is associated with high production rate cards, creates an increased amount of fly during operations because it does not retain its grip on fibers as effectively as fillet clothing. It typically must be accompanied by hood and exhaust systems.

Pneumafil Corporation, a major manufacturer of control equipment for the textile industry, testified in 1977 that it equipped 25,510 cards with some type of their control equipment between 1961 and 1976. Installations made after 1972 (7,000 cards) were warranted to achieve 500 ug/m^3 V.E.[17]

Sampling done for a 1980 NIOSH study found that using a chute feed system along with local exhaust ventilation achieved a mean dust level of only 172 ug/m^3 V.E.[18] Some old card systems sampled in 1977 had registered mean dust levels of 3210 ug/m^3.

These types of improvements were presumably in place in at least some of the mills in which the dust level measurements were taken that are mentioned by RTI and shown in Table 1, although the distinction, regrettably, is not clearly made. The NIOSH (1974) study predating the RTI study, had reported that:[19]

> The cast iron frames of many textile cards may be old, but the cards have been rebuilt and greatly modified during the past two decades. The throughput of cotton has been increased by two to five times on a large proportion of the cards. Dust

> production has been correspondingly increased. To compensate for the increased production of dust and fly, exhaust systems have been installed as card cylinder speeds have been increased. Unfortunately, there have been only a few studies of dust concentrations before and after modification and/or exhaust system installation. Wood and Roach investigated environmental conditions in four cardrooms to determine the effect of the latest system of exhaust ventilation. They found marked improvement insofar as total dust concentrations were concerned, but little change in the concentrations of the fine and medium sized fractions, i.e., dust less than 2 mm in size.

Other sources of dust include the pressure points in the housing of the licker-roll and feed roll (see Figure 4), points where the doffer comb takes the web off of the doffer cylinder, and manual cleaning of the machine. Card cleaning systems have been developed. (See Figure 5.)

One final source of dust during carding is attributed by the NIOSH study to the use of crush rolls on cards in many mills. These rolls pulverize bits of seed and leaf in the cotton so they will not interfere with, but drop out during, subsequent processing, primarily in spinning.

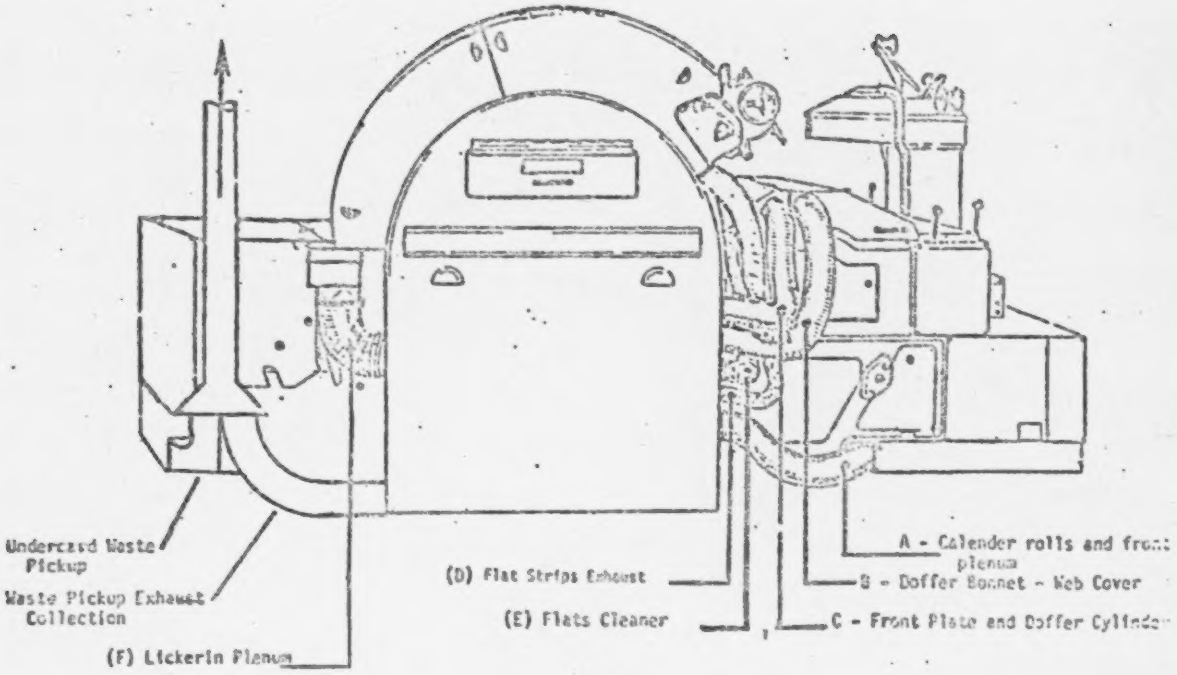
> "Again, there are not before-and-after environmental data, but the nature of the process would seem to assure increases in dust production at subsequent processes. The amount of lint-free dust which may be added by this process is not known. Because the active chemical agent in the dust is likely from the bract [the easily crushable leaf that grows under and around the cotton roll]... the proportion of active agent at subsequent operations may also be increased by the crush rolls."

Drawing

Drawing is the process in which several strands of card sliver, typically eight, are fed to a sequence of paired rollers in order to blend the fibers, to make them more uniform and more parallel. Each pair of rollers rotates at a higher surface speed than the preceding pair so as to attenuate the material as it is passed from one roller pair to the next. A single composite sliver is delivered from drawing and packaged in a can similar to that used in carding. Generally there are two drawing

FIGURE 5

CARD CLEANING SYSTEM


Undercard Waste Pickup
Waste Pickup Exhaust Collection
(F) Lickerin Plenum
(D) Flat Strips Exhaust
(E) Flats Cleaner
A - Calender rolls and front plenum
B - Doffer Bonnet - Web Cover
C - Front Plate and Doffer Cylinder

Source: Enviro Control, Inc., for NIOSH "Control of Technology Assessment of Raw Cotton Processing Operations." June 15, 1980.

processes.

The drafting action performed by the rolls loosens the fibers considerably, and short fibers frequently separate from the mass and collect on the rolls. If left on the rolls, these fibers would soon cause the cotton to lap on the rolls. Consequently, drawing frames are typically enclosed and use vacuum cleaning systems to remove those short fibers. The NIOSH study (1974) indicates that it is believed that draw frames do not seriously contribute to the dust load in the room for that reason. They do point out, however, that the air that is drawn through the suction system is returned to the room through filters. "As in other textile mill air cleaning systems, the filtration has not been designed to control respirable dust particles." Dust that is generated comes from the sliver passing over the creels, the drafting rollers, the coiler head and normal cleaning of the waste collection filter or chamber.[20] Reported dust levels in the drawing operation before the current standard ranged from 0.3 to 0.8 mg/m^3 (300 to 800 ug/m^3) V.E. (See Table 1.) Another source of dust in drawing is the manual cleaning of the waste collection chamber.

According to North Carolina Labor Commissioner John C. Brooks, in his 1982 Congressional testimony, in North Carolina local exhaust ventilation is available and used in drawing — mostly as a retrofit to current machinery. This ventilation brings the drawing process into compliance with the 1984 cotton dust levels. This is corroborated by Enviro Control's study for NIOSH, in which exhaust ventilation at drawing frames brought down dust levels to only 90 ug/m^3.[21]

Roving

The sliver from the drawing frames goes to roving frames which reduce the size and weight per unit length of the sliver by roller drawing, impart a slight twist for added strength, and wind the product on bobbins for spinning. The product ready for spinning is called roving. The drawing of the fibers against one another and the winding on bobbins produce an opportunity for further dust and short fiber to be released. Roving is not generally cited as a major source of dust problems,[22] but the one measurement shown in Table 1 does indicate levels of 0.5 mg/m-

(500 ug/m^3) V.E. (See Figure 6 for cross section of a roving frame.)

Spinning and Winding, Twisting, Spooling, Warping

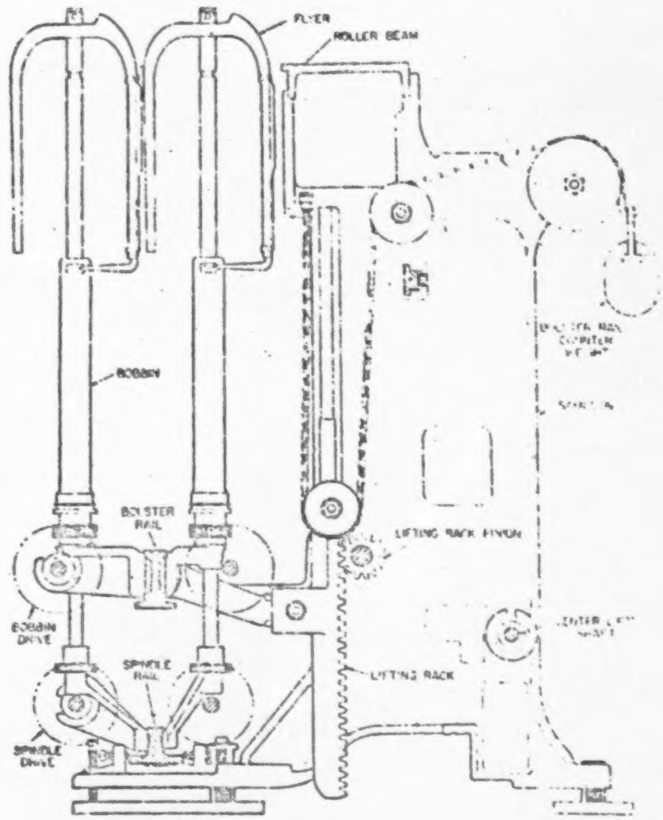
Spinning is the process by which fibers become yarn. It reduces the roving to the desired yarn size and imparts the amount of twist required for yarn strength.

The traditional spinning method is called "ring spinning." (See Figure 7 for cross section of a ring spinning frame.) In the first part of this process, bobbins are hung in a creel and ends are individually fed into drafting rolls. The twist is then imparted by passing the yarn through a traveler on a ring while it is being wound onto paper or plastic bobbins placed on a revolving spindle. Traveler speeds may be as high as 3,500 cm/sec. The combination of considerable reduction in yarn diameter and high air speeds across the yarn as it is spun creates the opportunity for release of a large proportion of the fine trash remaining at the spinning operation. Short fibers are also released so the concentrations of fly in the air can be appreciable. Because the loose fibers would interfere with the spinning process, some catching mechanism has always been used. The most common systems used in recent years are traveling blowers, which go alongside the spinning frames, blowing accumulated fly and associated trash off of them.[23] Vacuum sweepers are usually installed to suck up the lint and dust blown by the traveling frame cleaner.[24] The NIOSH report suggested that "in the absence of adequate controls, the problem of byssinosis could be expected to move forward from the cardroom to the spinning room because of the changes occurring in the modern mill." On the other hand, the RTI report said that:[25]

> Although the amount is not well documented, it is believed that the concentrations created in spinning areas are low. To eliminate waste, all spinning frames are equipped with a

FIGURE 6

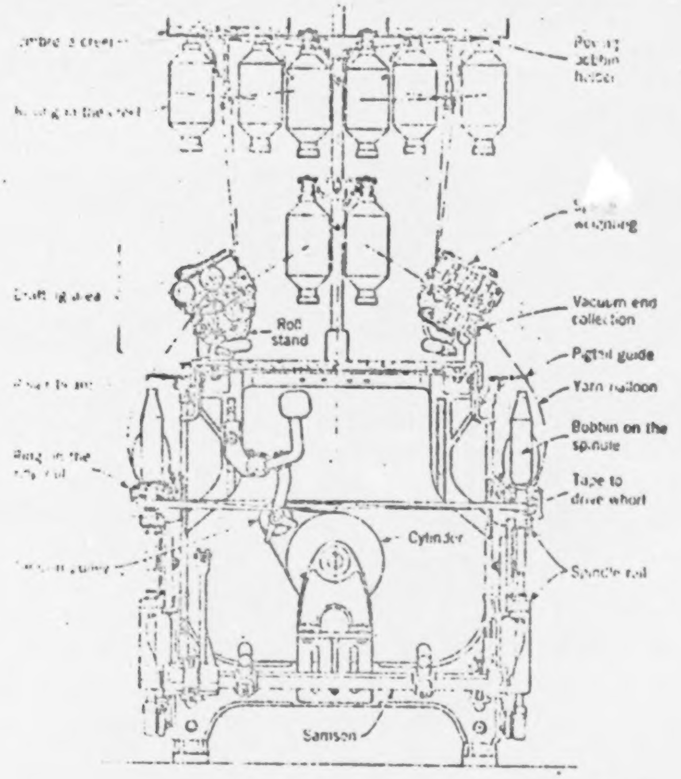
CROSS SECTION THROUGH THE ROVING FRAME


FLYER
ROLLER BEAM
BOBBIN
BOLSTER RAIL
BOBBIN DRIVE
SPINDLE RAIL
SPINDLE DRIVE
LIFTING RACK PINION
LIFTING RACK

The American Cotton Handbook, Volume I.

FIGURE 7

CROSS SECTION THROUGH RING SPINNING FRAME EQUIPPED WITH OPEN CREEL AND DOUBLE APRON DRAFTING SYSTEM.


Drafting area
Roll stand
Vacuum end collection
Pigtail guide
Yarn balloon
Bobbin on the spindle
Tape to drive whorl
Cylinder
Spindle rail
Samson

Reproduced from best available copy.

Source: The American Cotton Handbook, Volume I.

> "loose ends" collection system for cotton yarn that breaks in processing. This system captures the broken end and disconnects power to the machine via an electrical relay. The collection system, coupled by the fact that small amounts of trash remain as far downstream as the spinning frame, is itself believed to be sufficient to prevent airborne dust concentrations from exceeding 1 mg/m^3* total dust. In order to maintain even lower concentrations, the exhaust from the ends collection system, which is normally recirculated back into the room, is captured by an external dust collection device.
>
> ---
>
> *Note: See section on "Evidence of Respiratory Disease" for discussion of dose-response levels.

In other words, there seemed to have been some disagreement as to whether the measures taken to keep the machine clear of dust and lint for the processing itself were adequate to protect worker health. It would appear that the level of cotton dust exposure in spinning is quite dependent on the effectiveness of controls in earlier processes. According to North Carolina Labor Commissioner John Brooks, there is no effective ventilation available to control cotton dust in roving, spinning, winding, twisting, or spooling. But he says:[26]

> Good general dilution ventilation controls these exposures IF the processes proceeding roving are engineered to exposure levels below the 1984 cotton dust levels.

And, engineering controls in opening through drawing are clearly available and effective.

The dust levels prior to the standard for spinning operation (shown in Table 1) are 0.2-0.3 mg/m^3 (200-300 ug/m^3) V.E., which are much lower than for the other stages in processing. Testimony by an officer of the Pneumafil Corporation, however, raises questions as to the representativeness of those measurements. In his view, "the spinning frame is a maximum challenge for the cotton dust control engineer." He points out that the spinning frame is wide open from top to bottom and from side to side. This is essential because the traveling blower must be effective on all of the operating parts of the machine in order to control yarn quality. One blower cleans many frames by moving on overhead tracks. The dust and fly, as well as broken ends, go into vacuum ducts that run the full length of the frame into a collector unit at the foot end.

In the view of the Pneumafil officer, the structure of the conventional ring spinning frame posed virtually insurmountable problems for dust reduction. He listed four problems. The air and dust discharged at the collector unit could not be efficiently filtered before it was returned to the room because overhead blowers limited the space to accomplish this under the floor or on the roof, where it usually was not available. Dust thrown off by the spindle could not alternatively be captured at that point because that would require a barrier at each side of the frame, which would limit access for cleaning and increase the accumulation of lint and fly on the operating mechanism. "Massive" quantities of air could not be passed through floor openings, for still another alternative, because operating problems would be created. And finally, he felt full enclosure of the frames would be impractical. In summary, he indicated that the only practical approach was to capture and filter the air discharged by the broken ends collection system in those mills affected by the standard where underfloor space permits the installation of proper sized air handling ductwork. The best he expected from this was 0.5 mg/m^3 (500 ug/m^3) V.E., with some mills above that level.

Spinning has traditionally been very labor-intensive. "Between 50 and 70 percent of yarn manufacturing labor costs, opening through spinning, would arise in spinning. Costs of spinners and doffers would amount to 50 to 80 percent of spinning labor costs. High labor costs thus involve cleaning, piecing, doffing, maintenance and transportation."27 There has always been a strong impetus to try to reduce those costs with the installation of more modern equipment -- especially equipment which reduces ends down and repairs broken threads automatically. With such modern equipment demands for manual work are reduced. By the mid-1970s, a new technology, called "open-end" spinning, was emerging to answer that need. This technology apparently provides answers to the problems raised in controlling dust in conventional ring spinning as well. In addition, the production rate is four to five times that of a ring spindle.28

In the relatively new technology of open-end spinning, (See Figure 8.): 29

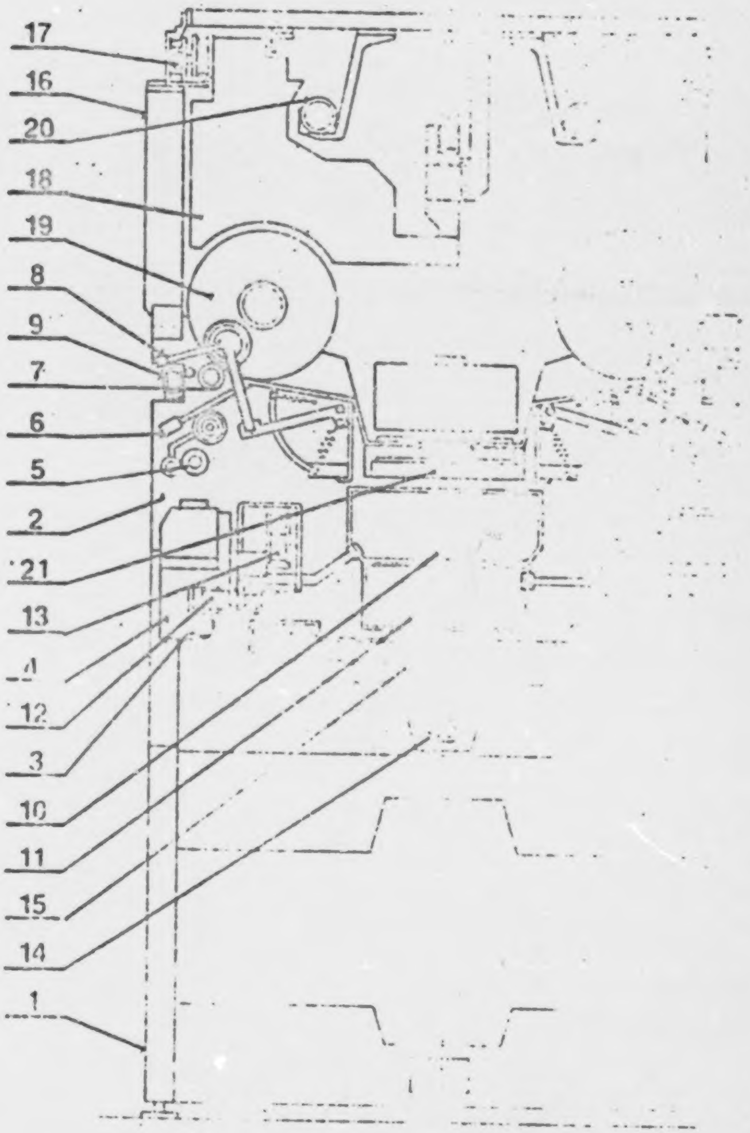
> "the open-end frame is supplied with sliver from a draw frame (obviating the need for a roving frame), passes sliver through a drafting system into a centrifugal rotor and, thence, to a wound package (obviating the need for a subsequent winding operation)....The open-spinning concept lends itself beautifully to the complete systems approach. This says that if a completely automated system (now available) be installed, from raw bale through finished sliver, and if open-end spinning be installed to operate from sliver, through winding, then there would be two basic processes which would replace eight conventional processes."

In addition to the labor and cost saving features in combining separate steps, the open-end spinners were said to greatly reduce the fly in the room because opened fibers are sucked into the rotor.30 There do not, however, appear to be any specific measurements of dust levels created by open-end spinning dating from the period prior to or during which the 1978 OSHA standard was being considered. However, a 1980 study for NIOSH showed the mean dust levels for air samples to be only 100 ug/m^3 V.E.for open end spinning.31

By the mid-1970s, open-end spinning was becoming a well accepted technology. In 1974, ATMI reported that there were in place 73,160

FIGURE 8

CROSS SECTION OF OPEN END SPINNING MACHINE



Cross section of BD-200-SI machine

1. Base
2. Side frame
3. Feeding shaft
4. Spinning unit
5. Take-up mechanism
6. Spinning-in lever
7. Winding roller
8. Winding arm
9. "Third hand" suction duct with yarn distribution
10. Technological air outlet duct
11. Impurities outlet duct
12. Fibre opening system drive
13. Spinning rotor drive
14. Channel for electric installation
15. Channel for collectors
16. Energy block
17. Air channel for the doffer
18. Doffer
19. Full bobbin
20. Tubes magazine
21. Cheeses transporter

Reproduced from best available copy.

Source: Investa, "Rotor Spinning Machine."

spindles of open-end spinning, with additional ones on order to bring the total to 168,000 through 1976. Open-end spinning allows for higher yarn counts, eliminates drawing and roving, and allows for dust reductions. (See Section IV on Spinning, for greater detail.) There are, however, some limitations on the types of fibers that can be spun in this manner. Open-end spinning is well adapted to coarse yarns, with counts up to 29 but not yet to finest yarns. Improvements in the technology, allowing for greater versatility with yarn types, are being achieved and more are expected. A 1983 study for OSHA found that open-end spinning equipment currently available is "third generation," and each "generation" produces equipment improvements.[32] Whereas yarn strength in open-end spinning had previously been only 30 to 50 percent the strength of ring spun yarns, "third" generation equipment produced yarn 80 percent as strong as similar ring spun yarns. Open-end spinning may not ever be adaptable for every spinning need, but recent expert opinion says that "it is not [yet] known whether the yarn texture problem can be overcome by modifications or improvements to open end equipment."[33]

After traditional ring spinning, the yarn is usually removed from the spinning frame bobbin and placed onto larger tubes or cones. The purpose is to combine several bobbins and to remove thick places from the yarn. The winding operation is conducted at high speeds, which can cause considerable release of foreign matter that has been carried through from previous operations. The NIOSH report indicates that "both high prevalence of byssinosis and relatively high dust concentrations have been noted in winding operations."[34] But the RTI report suggests that while some dust is produced, "the trash content of the cotton fiber presented to the winder is extremely low." It is the trash content from the cotton plant which is believed to contain the active toxic agent responsible for byssinosis. Table 1 shows measured dust at the 0.3 mg/m^3 (300 ug/m^3) V.E. level. Winders rarely have any provision for removal of dust and lint from the air, and are seldom provided with dust control collection devices by vendors. On open-end spinning frames the yarn is wound directly onto larger tube or cone packages.

Spooling is a specialized form of winding that includes a mechanism to remove debris from the yarn. The resulting dust and lint is usually filtered, but some dust is allowed to pass back into the room.

Twisting combines two or more strands of yarns to form ply yarns. The NIOSH study suggests that by that point in the process there is little active agent left to be released.

Warping is the process in which several hundred individual strands of yarn are formed into a parallel sheet and wound onto a warp beam for slashing or dyeing. In the first stage, 300 to 600 ends from winder packages are wound onto a section beam. At the second stage, the slasher combines the sheets of yarn from 4 to 10 section beams, passes them through a box to apply the size, across drying cans, through rods which split the yarns in the sheet back down to individual ends and finally winds the yarns on a loom beam. The yarns on the loom beam serve as the warp (lengthwise) portion of the woven fabric. The RTI study, done prior to the issuance of the standard, notes that:[35]

> "Although not well documented, considerable lint is liberated in the creels and at the comb of the warper. As warping occurs late in the line of cotton processing, it is again suspected that little active toxic agent remains in the processed yarn. Elutriated dust concentrations of approximately one mg/m^3 may occur in slashing/warping."

Weaving

Weaving transforms the yarn into fabric by interlacing warp (lengthwise) and filling (widthwise) yarns at right angles. The pattern is determined by the placement of specific warp yarns on the face or back of the fabric for each pick inserted. The placement is controlled by raising or lowering a particular harness.

Dust is released by abrasive action on the warp yarn during the raising and lowering of the harness and during beating up movement of the reed back and forth along the warp yarns. The reed moves back before filling is inserted and forward after filling insertion.

According to the American Cotton Handbook,:

> In any weave room producing cotton fabrics, there is a problem of lint and starch which sheds from the yarn. This waste, being light, becomes airborne, then is deposited on the loom, ceiling, and floor. In just a matter of hours, this waste can accumulate to the point of being a serious hazard to the quality of the cloth.
>
> Small particles of lint and starch will be deposited on a loom, and, as these deposits increase in size they soon will become sufficiently large that the vibration of the loom will shake them loose. If they fall on the warp yarn, they may cause excessive ends down, as well as soil or stain the yarn.
>
> Looms may be cleaned manually, from once a day to once a week, depending on local conditions. In order to hand clean with an air hose, the loom must be stopped.
>
> A more efficient, automatic and continuous method of cleaning looms is in the use of an overhead blower, mounted and traveling on a track, so that the cleaner passes over each loom at definite intervals. This cycle is usually from 8 to 12 minutes.

Because of the widespread use of blowers, and because workers must have access to both the front and back of the loom, looms are, like spinning frames, completely open. The extent of the dust hazard they present appears to be a matter of contention.

The RTI study takes the position that since woven cloth is considered to be an end product in yarn processing, little active agent remains to be released.[36] The SRRL study suggests that because of the high humidity in the weave room, the particles that are released are heavy and settle to the floor without becoming airborne.[37] The study in North Carolina indicates that dust in the weave rooms generally is made up of components that are added to the yarn and are not associated with byssinosis — and that both old and new looms meet the required dust levels in most textile weaving operations.[38] Nevertheless, Table 1 shows, prior to the regulations, measured dust levels from 400 to 1100 ug/m^3 V.E. And the NIOSH study concludes that "while byssinosis of the severity encountered at carding would not be expected, various health effects have been noted among weavers."[39]

A problem generated by the new generation of shuttleless weaving machines is that of oil mist. Oil mist is used to lubricate the shuttles which insert filling yarns into the fabric. While the mean dust level V.E. without oil mist has been estimated at 127 ug/m^3 V.E., with oil mist the level climbs to 879 ug/m^3; i.e., 86 percent of the "dust" reading may really be oil mist.[40] Still even 879 ug/m^3 is within the OSHA compliance level.

Chapter II

Regulatory History

Evidence of Respiratory Disease

The respiratory problems associated with cotton dust have been recognized for a long time. There is no known safe level of exposure. The disease associated with cotton dust is "byssinosis," sometimes called brown lung. Symptoms include chest tightness or oppression, dyspnea, difficulty in getting air into the chest, coughing, wheezing and such nonrespiratory complaints as malaise. In advanced stages of the disease, an individual becomes oxygen dependent and may die. Death may be from infection, respiratory failure or heart failure (the result of excessive strain on the heart caused by impaired lungs).

A grading system for the disease has been developed[41] and refined over the years:[42]

— Grade 1/2: occasional chest tightness on the first day of the working week.

— Grade I: chest tightness and/or breathlessness on Monday only.

— Grade II: chest tightness and/or breathlessness on Mondays and other days.

— Grade III: grade II symptoms accompanied by evidence of permanent incapacity from diminished effort intolerance (sic) and/or reduced ventilatory capacity.

The first three grades are generally reversible, but the last is usually irreversible.

Historic reports of the disease date from 1713 when Ramazzini wrote of "disease of dressers of flax and hemp." He observed that "a foul and poisonous dust flies out from these materials, enters the mouth, then the throat and lungs makes the workers cough incessantly and by degrees brings on asthmatic troubles."[43] Local clinicians in France and England reported on byssinosis disease through the 19th and early 20th centuries. The British Home Office issued an official report in 1931 which linked cotton textile work with respiratory disease. But, in 1933, the U.S. Public Health Service concluded that dust concentrations were too low to adversely affect the health of workers.[44]

Times changed, however, and cotton dust became regulated by the federal government of the United States for the first time in 1968, when the U.S. Secretary of Labor included raw cotton dust as part of a list for coverage under the Walsh-Healey Act (41 U.S.C. 35 et seq.). The threshold limit value (TLV) under Walsh Healey was 1000 ug/m^3, and represented a value set tentatively in 1964 and formally adopted in 1966 by the American Conference of Governmental Industrial Hygienists (ACGIH). Actual federal involvement at this time was minimal, with the states having primary responsibility for workplace safety and health.

With the passage of the Occupational Safety and Health Act of 1970, the Occupational Safety and Health Administration (OSHA) was founded. OSHA adopted the 1000 ug/m^3 standard as an established Federal cotton dust standard under section 6(a) of the OSHAct.

In 1971, ACGIH reviewed the work of Bouhuys[45] which had found 17 to 28 percent byssinosis at cotton dust levels averaging close to 1000 ug/m^3. Other research on the health problems associated with cotton dust continued, especially in England. In 1972, th British Occupational Hygiene Society published a report recommending a new standard for Britain of 500 ug/m^3. An effort was also underway to measure respirable dust rather than total dust. By 1974, the ACGIH adopted a TLV of 200 ug/m^3 of cotton dust as measured by the vertical elutriator.* This was followed that same year by a recommendation by the Director of the National Institute for Occupational Safety and Health (NIOSH) that "the concentration should be set at the lowest feasible level, but in no case at an environmental concentration as high as 0.2 mg lint free cotton dust/cu m [200 ug/m^3], in order to reduce the prevalence and severity of byssinosis."[46]

December 27, 1974, OSHA published an Advance Notice of Proposed Rulemaking (39 FR 44769) requesting that interested persons submit their views on specific issues relating to cotton dust, particularly the NIOSH Criteria Document. Two years later, in December 1976, OSHA published a proposal to revise the existing standard for occupational exposure to cotton dust (41 FR 56498). The proposal called for a permissible exposure limit (PEL) of 200 ug/m^3 of vertical elutriated cotton dust for all segments of the cotton industry.[47] Out of concern for feasibility, the proposed PEL was at the high end of the NIOSH recommendation of 1974. Hearings were held.

OSHA studied the research findings of many expert scientists. Work by Schilling, Berry, Imbus and Suh, Braun and Bouhuys all found reduced respiratory function among cotton textile workers. OSHA determined through the hearing process that:[48]

> "the overwhelming scientific evidence in the record supports the finding that cotton dust produces adverse health effects among cotton workers (Exhibit 1, Exhibit 11, Exhibit 13, Exhibit 19, Exhibit 12, Exhibit 38, d). The disorders range from an acute reaction manifested by a depression of pulmonary

---

*Note: Several sampling devices have been used to measure dust. Use of vertical elutriator has become common because it allows measurement of short-term samples (approximately 7 minutes) and avoids the time consuming weighing procedure. (See appendix for definition

> function indicators, or by subjective symptoms such as chest-tightness, shortness of breath, or cough, to a stage characteristic of chronic obstructive pulmonary disease which is often disabling (Exhibit 48, p. 1; Exhibit 6 #17, 20, 21, 42, 43, 57, 54, 56)."

The OSHA hearing record contains disorders ranging from the acute symptoms of Grade 1/2 through II to the chronic symptoms of Grade III.[49] Beside symptoms, NIOSH provided the OSHA record with studies of decreased pulmonary function measurements in FEVs (Forced Expiratory Volume) and FVCs (Forced Vital Capacity). Virtually all medical witnesses at OSHA hearings, including those from industry, testified that "prevention of chronic obstructive pulmonary disease should be pursued vigorously...[50]

Of the more than half a million workers potentially exposed to cotton dust, in 1979, an estimated 84,000 active workers suffered from acute byssinosis and at least 35,000 employed and retired textile workers were disabled from dust-related diseases. These numbers are thought to be underestimates because many cases of disabiling or fatal byssinosis are not recognized as occupationally related.[51] The active agents responsible for byssinosis are not yet known. But, in cotton dust, it appears to be the trash component — probably from the bract of the cotton plant.[52]

It was further determined that "at the present time there is no basis for any programs of prevention and control of byssinosis other than those used on prevention of exposure to respirable cotton dust."[53].

The distribution of acute byssinosis varies throughout a mill, and changes as facilities and processees are altered. It appears that millworkers in the early stages of cotton processing incur the highest risk. Recent studies in the United States show a byssinosis prevalence of 20 to 30 percent among cardroom workers and as much as 70 percent of the work force in early stages of processing may be affected, especially if coarse, dusty cotton is being processed. Workers in later stages of cotton processing appear to incur a lower risk of byssinosis. For example, a study by Bouhuys reports the average prevalence of byssinosis among 431 workers in slashing and weaving to be approximately 13 percent.[54]

There are several studies of dose-exposure levels. Evidence presented by Merchant to OSHA documented byssinosis prevalences of seven percent at 100 ug/m^3 for untreated cotton in cotton preparation and yarn areas, 13 percent at 200 ug/m^3 and 26 percent at 500 ug/m^3. In weaving the dose-response curve shifted downward to no byssinosis prevalence at 200 ug/m^3, five percent at 500 ug/m^3 and 15 percent at 1000 ug/m^3. (See Table 2.) This lower prevalence is because of the inclusion of inert sizing in the dust measured in weaving rooms.[55]

Pooled data of the American Textile Manufacturers Institute (ATMI) found 11.3 percent prevalence associated with dust measurements greater than 500 ug/m^3 and 4.4 percent for dust levels below 500 ug/m^3.[56] (See Table 2.)

NIOSH review of work by the British Occupational Hygiene Society Committee on Hygiene Standards found a prevalence of byssinosis which ranged from a low of 1.5 percent for exposures less than 50 ug/m^3 to 55.0 percent for exposure levels of 400 to 500 ug/m^3.[57] (See Table 3.) Research by Molyneux and Berry, and Imbus and Suh indicates byssinosis associated with some exposure levels so low as to be effectively zero.[58] OSHA recognized the "absence of any known 'safe level of exposure.'"[59]

The Current Standard

After careful review of all the available evidence, data and expert opinions, OSHA on June 23, 1978, issued its final mandatory occupational

Table 2

Prevalence of Byssinosis

Process / Exposure ug/m^3	Cotton Preparation and Yarn Areas (OSHA)	Weaving* (OSHA)	All Processes (ATMI)
100	7%	—	
200	13	0	↑
500	26	5	4.4
1000	—	15	↓ 11.3

*Includes inert sizing in the dust.

Source: U.S. Department of Labor, American Textile Manufacturers Institute, Federal Register.

Table 3

Prevalence of Byssinosis
Compared to Known Dust Exposures

Total Dust Exposure ug/cu m	Prevalence*		No. of People Examined
0 - 50	1.5%		212
50 - 100	2.8%		108
100 - 200	9.9%		1,259
200 - 300	8.5%		1,226
300 - 400	34.0%		465
400 - 500	55.0%		245
500 - (3400)	27.5%		92
		Total	3,607

*Byssinosis all grades.

Source: NIOSH (From British Occupational Hygiene Society Committee on Hygiene Standards.)

safety and health standards on occupational exposure to cotton dust (29 CFR 1910.1043).

Both economic and technological feasibility were studied. There was general agreement on the technological feasibility of 200 ug/m^3 for opening through roving, but there were differences of opinion on the potential difficulties of compliance at later processing stages. RTI suggests ventilation as the primary method for reducing exposure to cotton dust. The ability to design in effective control technology on new equipment was also noted. But OSHA concluded that the PELs of the standard could be met with current level technology.

Economic costs of compliance were estimated by OSHA to be $656.5 million for capital costs and $206.1 million per year[60] -- costs which OSHA concluded were feasible for the industry. Figures were developed from analysis of the RTI study and from testimony by industry at the hearings. (See Table 4.) The major industry source was a study done by Hocutt-Thomas for ATMI. Economic costs included not only engineering controls, but also work practices, monitoring medical surveillance, respirators, training, signs and recordkeeping.

The final standard established permissible exposure limit of 200 ug/m^3 for yarn manufacturing, 750 ug/m^3 for slashing and weaving operations, and 500 ug/m^3 for all other processes in the cotton industry and for non-textile industries where there is exposure to cotton dust. Cotton ginning was the subject of a separate regulation, which has since been vacated by court action.

Changes, from the proposed OSHA standard of 200 ug/m^3 for all cotton textile manufacturing process to the final levels were based on the hearing record.[61] Weaving and slashing in the standard are subject to a

Table 4

Comparison of Estimates for Capital Cost of Compliance
OSHA Cotton Dust Standard
(millions of dollars)

Preregulatory	Current Dollars	Constant Dollars (1982)
RTI (1974)	$993.5	$1,941.3
RTI revised (1974)	699.9	1,367.6
Hocutt-Thomas (1977)	550.0	874.6
OHSA preregulatory estimate (1978)	656.5	970.1
Postregulatory		
Centaur (1982)	245.0	245.0

Sources: Federal Register, Centaur.

750 ug/m^3 exposure level. The higher PEL was allowed because:

1. The Merchant data showed a different dose-response relationship for weavers; i.e., zero at 200 ug/m^3, 5 percent at 500 ug/m^3 and 10 percent at 750 ug/m^3. Other studies also found reduced evidence of byssinosis in weaving areas.

2. The dust in weaving rooms is primarily of sizing materials.

3. The record suggests that engineering controls may not be feasible at 200 ug/m^3 for weaving.

4. A PEL of 750 ug/m^3 for weaving would be as safe an environment as 200 ug/m^3 for other operations.

Nontextile industries were held to only a 500 ug/m^3 PEL because:[62]

1. Of a lack of definitive data in the OSHA record.

2. Of Dr. Merchant's opinion that 500 ug/m^3 was appropriate for nontextile industries.

3. Adverse effects of dust in nontextile industries may be less than in textile manufacturing.

4. RTI doubted the technological feasibility of a 20 ug/m^3 standard.

The standard was to become effective September 4, 1978, but court challenges interfered with implementation. Five cases were taken to the U.S. Court of Appeals (see Table 5) and one to the Supreme Court of the United States. Interestingly, the U.S. textile industry did not challenge the technological feasibility of the standard. In its brief before the Supreme Court in 1980 challenging the OSHA cotton dust standard, the industry never denied that the standard was technologically feasible.

In setting the limit, OSHA recognized that it would not eliminate byssinosis. But the agency had determined that 200 ug/m^3 of respirable cotton dust was the lowest feasible level. The Amalgamated Clothing and Textile Workers Union and Carolina Brown Lung Association had lobbied hard for a 100 ug/m^3 level.

Table 5

LITIGATION

SUBSTANCE	INDUSTRY SEGMENT	COURT	CITATION
Cotton Dust	Ginning	U.S. Court of Appeals Fifth Circuit	Texas Ind.Ginners Assoc. v. Marshall 630 F.2d 398 (1980)
	Cottonseed Oil	U.S. Court of Appeals District of Columbia Circuit	AFL-CIO et al v. Marshall et al 617 F.2d 636 (1979)
	Waste processing	U.S. Court of Appeals District of Columbia Circuit	National Association of Manufacturers v. Donovan, No. 78-1784 and consolidated cases
	Classing and Warehousing	U.S. Court of Appeals District of Columbia Circuit	Cotton Warehouse Assoc. v. Donovan, No. 78-1736
	Textiles	U.S. Court of Appeals District of Columbia Circuit	AFL-CIO et al v. Marshall et al 617 F.2d 636 (1979)
	Textiles	U.S. Supreme Court	American Textile Manufacturers et al v. Donovan, 101 S.Ct. 2478 (1981)

The Supreme Court in case no. 79-1429 on June 17, 1981 upheld the PELs as established by OSHA. Respirator usage was permitted during the four-year interim period allowed for the installation and implementation of engineering controls. Compliance is required by March 1984.

Chapter III

Relationship Between OSHA Regulations and the Development of New Technologies

To what extent do OSHA regulations promote the development of new technology in the workplace? Without regulatory or economic incentives to provide safe and healthful workplaces, new technological improvements for safety and health are unlikely to emerge. Scientists and engineers are not likely to be hired for purposes of developing safe equipment and production processes; researchers are not likely to incorporate safety and health into their criteria for a successful project. When the major proclaimed objective of private sector business activities is financial success, then unless something is viewed as contributing to a maximization of profits or to a minimization of costs, it is not likely to be undertaken. In the past when new equipment or new procedures increased both productivity and health and safety it was usually coincidental. Health and safety activities would usually have been initiated only if there was a shortage of labor or if expenditures for employee disability, disease or illness was so high that it would merit correction in order to minimize costs. Although concern for social justice or equity can influence business decisions, a company's financial viability and profitability may limit that concern.

Post-regulatory experience increasingly documents the emergence of modified and emerging technologies in many industries soon after the promulgation of a safety or health standard. The advent of a strong federal occupational safety and health law may change the economic incentives, as well as legal reality.

If businessmen assume that government regulations will be enforced, and, therefore, that they must comply with them, then rational businessmen will seek the most efficient method of compliance. Not only is retrofitting of equipment costly, but it does not provide opportunities to make capital investments which in themselves will also increase the productivity of capital in place. An expenditure on enclosures and other retrofits, while it may improve worker health and safety, is likely to be a drain on profit potential. But an expenditure on the newest and latest production technology may increase both productivity and health and safety.

Many people have tried to establish a clear, simple, causative and quantitative relationship between regulation and technology. While this could be a fascinating exercise, it is not very useful since the decision by a firm to try new innovative techniques is usually the composite result of examining many factors. There are the general considerations of any investment decision, such as: What are the profit levels of the company? The debt structure? The amount of working capital? What are the applicable interest rates? What useful life, if any, is there to existing capital? What economic life? Financial investment decisions are also affected by applicable tax law including such federal legislation such as the 1981 Capital Recovery Act or the 1981 Economic Recovery Act. There are also considerations much more specific to the technology itself. These include: What new technology is available? What is the competition doing? How will it affect costs, profits, product quality, energy expenditures, etc.? How well tested are the techniques involved? What kind of machine servicing is available? How soon could this new generation of equipment itself become out-of-date? And, increasingly, through the 1970s, how will this equipment help in compliance with government regulations?

Technology Forcing and OSHA

Experience with a wide variety of OSHA regulations over the 12 years since the passage of the Occupational Safety and Health Act has provided evidence of "technology-forcing." Especially well-documented is the case of vinyl chloride. Industry representatives argued before the promulgation of the standard that an OSHA regulation might be a collapse of the entire industry, with a cost to the U. S. economy of nearly $2 billion. However, within 18 months of promulgation of an OSHA standard for vinyl chloride, the industry was nearly in compliance and the capital costs were estimated at $200 million dollars or less.[63] At the same time, at least six important new innovative techniques had been put in place in the vinyl chloride industry which not only moved the industry toward compliance with the OSHA standard but which also increased industry productivity. These ranged from the development of a new and more efficient polymerization process to new procedures to tighten pipe flanges and to permanently weld pipes together. Other cases involve simultaneous production and health and safety improvements in copper refining, lead acid battery manufacturing and others.[64] Through modernization in the cotton textile industry, there have also been simultaneous improvements in both productivity and in lowering dust levels in the plants. Technology-forcing seems to be at work.

OSHA has technology-forcing authority. The standard setting process within OSHA requires, according to Section 6(b)(5) of the Act, that the proposed standard be feasible. That feasibility includes both technical and economic considerations. These considerations, however, need not be governed only by technology already in place. In fact, in contrast to techniques that have been used by OSHA and others to estimate the expected costs of regulation, decisions made by the Secretary of Labor concerning standards are not bound by "current level technology only." When making decisions on vinyl chloride, coke oven emissions and inorganic lead the Secretary of Labor went beyond then current technology. The courts have also refused to confine the authority of the Secretary of Labor, in reducing exposure levels to toxic substances, to the capabilities of fully developed technology; i.e., the diffusion of an already fully commercialized technology from a few firms to all firms within an industry, or even diffusion from one industry to another. The post-hearing brief by OSHA on its lead standard confirms the fact that:[65]

> ...The Secretary is authorized, where it is warranted to protect employee health, to set standards requiring 'improvements in existing technology' or the 'development of new technology' (i.e., 'surpassing that currently in use in even the leading firms'), so long as the record demonstrates the 'potentiality of improvements or new developments.'

Three different court decisions support the technology-forcing authority of OSHA. In *AFL-CIO v. Brennan*[66], the Third Circuit Court held that OSHA can impose a standard which only the most technologically advanced plants in an industry have been able to achieve — even when that technology is only in a few plants and only in some of their operations. In *American Iron and Steel Institute v. OSHA*,[67] the courts went still further, ruling that OSHA could also force industry to develop and diffuse new technology. This more far reaching view of technology forcing was also supported by a Second Circuit Court decision, *Society of the Plastics Industries, Inc. v. OSHA*.[68] This ruling said that as long as OSHA gave industry a reasonable time to develop new technology, that OSHA was not bound by the status quo. It also determined that as long as there is substantial evidence that companies acting both vigorously and in good faith could develop technology, OSHA could require industry to meet PELs never before attained.

Since the inception of OSHA, there has been movement away from specification standards, which dictate to industry exactly how and with what technology they may solve a problem. Instead, OSHA has increasingly focussed on performance standards which tell a company what level of safety and health they must achieve, but then leave the method of control open to the company's choice. Performance standards have been used most often in the promulgation of safety standards.

Performance standards encourage companies to seek new and more efficient ways to achieve compliance with OSHA standards. Performance standards give companies the flexibility to experiment with new ways to achieve compliance, sometimes with the result of achieving not only health and safety compliance but of simultaneously achieving increased productivity, energy savings, improved product quality or salable byproducts as well. Performance standards allow an overall system review of a given problem. By allowing a company to use a systems approach to meet a regulatory challenge, one can usually minimize the burdens of regulation. In fact, one can expect a greater possibility of new and innovative techniques. OSHA has learned that performance standards are one way to make the regulatory process more efficient as well as less burdensome to industry. In addition, the variance process, whereby a company can gain special exceptions to a rule, also gives a company added flexibility.

Pre-Promulgation Debate on Textile Industry Technology and Costs

Technological developments for the textile industry have been on the horizon for a long time. While new technology has been refined since 1978, most of the new systems currently being put in place had already been developed by them. In 1978, the preamble to the OSHA cotton dust standard, concluded that "the evolution of new technology has and is expected to continue to provide additional means of achieving lower dust levels and increasing production."[69] Nonetheless, OSHA's consultant, prior to promulgation, RTI, had not viewed technological developments as a major solution, but had instead decided that compliance would come mainly through ventilation, modification or isolation of the process, work practices, and substitution. Most of these solutions involved expenditures which added nothing to productivity.

The RTI report assumed that control technology would have little or no role in compliance efforts. The document is premised on the assumption that "process modification, other than improved maintenance, has had little effect on dust concentrations,"[70] in yarn production and that "the capture and removal of dust from the air at the point of generation (i.e., local exhaust ventilation) appears to be the most efficient method of dust control at the present time."[71] Actual post-regulatory practice has proven the report wrong.

The Amalgamated Clothing and Textile Workers Union (ACTWU) challenged the assumption during the pre-promulgation debate, claiming that control technology could in fact play a major role. In their statement to the Occupational Safety and Health Administration in April 1977, the union asserted that "the RTI premise is wrong."[72] They went on to say:

> "Process modification has had a major effect on dust concentrations in yarn production. Indeed, those textile companies which have substantially reduced dust levels in their plants — and there are many which have done so — have

> relied primarily on the more modern machinery which has become available in recent years to accomplish their goal at a small fraction of what it would cost by means of the strategy assumed by the RTI, i.e., the use of retrofitted ventilation devices."

During the cotton dust rulemaking, the nature of available technologies was debated. Some experts argued that solutions to the cotton dust problem would require the kinds of diversion of resources discussed by RTI. Most industry spokesmen took this point of view. ACTWU, on the other hand, argued that there was already evidence that "technological advances based on automating and improving the manufacturing process have been preferred by employers to applying ventilation controls."[73] One of the union's consultants, Dr. Parker Reist, explained that:[74]

> "When considered with available modern machinery designs, incorporating higher production rates, labor savings, and improved product quality, will often result in lowering dust levels to within the range of the permissible exposure limit herein prescribed, while at the same time, offering economic advantages."

OSHA in its rule setting process, while acknowledging the likelihood of technological developments forming more efficient solutions than ventilation and enclosures (the main RTI techniques), decided that "compliance with the cotton dust standard by all segments of the industry depends upon the implementation of general principles of control and should not require technology-forcing to achieve compliance."[75]

There is still a debate on the extent to which resources have been diverted from productive investment to the "defensive" investments needed for compliance purposes only. Most textile manufacturers are hard put to state the specific dollar amount spent on capital for OSHA compliance because control technologies so closely integrate productivity improvements with health and safety improvements. This close integration of several different improvements is also acknowledged by OSHA's 1983 consultant on cotton dust, Centaur. Centaur acknowledged that if it was to estimate OSHA compliance costs, it would have to do more than simply cost out equipment:[76]

> Because the production equipment which is installed to help facilitate compliance with the OSHA standards has certain production advantages, the following methodology was used to estimate the portion of expenditures for such production equipment which can be allocated to OSHA compliance.*

Pre-promulgation and court debate brought threats and innuendos than at OSHA cotton dust regulation could bring financial ruin. As an example, in an ATMI legal appeal against the OSHA standard argued that "the standard is prohibitively expensive because it imposes extremely severe financial burdens on a vulnerable industry."[77]

Several estimates of the capital costs of complying with the OSHA cotton dust standard have been made over time. They are difficult to compare one with another because of the differing methods of cost estimation that each used. It is the author's view that each independently also has some serious flaws of its own. Nonetheless, the difference between the estimates made before promulgation of the standard and the much lower estimates made afterwards is clear. (See Table 4.) Research Triangle Institute (RTI), as a consultant to OSHA before promulgation of the standard, initially projected total capital costs of $993.5 million (in 1974 prices). This estimate was later reduced by 30 percent to $699.9 million to eliminate controls on equipment which processed only synthetics. The American Textile Manufacturers Institute presented a study done by Hocutt-Thomas which established the total cost of capital for compliance (in 1977 prices) at $550.0 million.[78] OSHA finally, itself, estimated the cost to be $656.5 million (in 1978 prices).[79]

---

*Note: Centaur determined that 17.5 percent of production equipment purchased by textile manufacturing firms was allocable to OSHA. While this acknowledgement is a definite step forward in the methods used for estimating the costs of OSHA compliance, it should be noted that the assumptions made by Centaur are themselves problematic. Centaur compared the rate of investment for new cards in 1977 with the rate in 1982 and attributed the difference to OSHA. It then extrapolated from cards to the entire industry. What Centaur failed to acknowledge was that there may be a natural increase in the rate at which textile machinery is turning over due to substantial productivity gains of the newest generation of equipment. (See next section for some specific examples.) Federal legislation to promote investment, passed in 1981, may also have worked to increase investment. In addition, decisions about other investments in textile machinery are being made, outside of carding, which may not be closely parallel to investment decisions for new carding systems. For example, while shuttleless looms have some cotton dust improvements, their noise control improvements are more substantial, and their triple productivity rates are even more likely to be a more important cause of accelerated investment.

But, as discussed earlier, estimates made before an OSHA standard has been promulgated are usually much higher than what they actually turn out to be. (See Table 4.) In a 1982 study done for OSHA, in which 60 percent of capital investments had already been made, and almost all other investments to achieve compliance had been planned for and costed, total capital costs (in 1982 dollars) were expected to amount -- not to $500 million, $600 million or $900 million — but to $245 million.[80]

The large overestimate in the preregulatory debate is obvious, but is even more pronounced, as well as more correctly portrayed, if prices are all given 1982 dollar value. Comparing dollars of like value, the initial RTI estimate was nearly $2 billion and the OSHA capital cost estimate before promulgating the standard was at least $970 million, compared to OSHA's current estimate of $245 million. (See Table 4.) The initial RTI estimate before the promulgation was nearly 10 times the current estimate and the OSHA estimate was more than 3.5 times higher than current estimates. In four years, the economic package for capital investment emerges quite differently than the agency thought it would. This is becoming a pattern for retrospective views which compare cost estimates made before and after the promulgation of a standard.

Technological Change in The Textile Industry Level of Compliance After Two Years

Since implementation of the standard, substantial progress has been made in compliance. The Stevens Company says its plants are 87 percent in compliance with the OSHA cotton dust regulation. Industry spokesmen including those at ATMI, are using a rule-of-thumb of around 75 percent compliance. Many of the newly modernized plants are already totally in compliance with the law. In July 1981, the state of North Carolina mailed questionnaires to the 992 North Carolina companies affected by the OSHA cotton dust standard. Of those replying, through the end of 1981, in every area of production at least half the companies believed themselves in compliance with the 1984 PELs. In over half the production areas, more than 80 percent of the companies claimed they were already in compliance, with 2 1/2 years still left before compliance was required. (See Table 6.)

Some problem areas, however, may exist for some firms and some processes. Dust control equipment manufacturers will not always guarantee compliance with the 200 ug/m^3 PEL for ring spinning, spooling, winding and twisting.[81] But the progress in four short years is very impressive.

Whereas 35 percent of active exposed textile workers in 1978 worked in areas of dust above the level of the standard, by 1982 the percentage had been cut nearly in half. Results of a recent study for OSHA by Centaur Associates found that in 1982, "about 81 percent of the active exposed worker population was estimated to be at or below the current

Table 6

Percentage of Companies Claiming Compliance With the PEL in 1981

Area	PEL in ug/m^3	% in Compliance
Opening	200	53
Picking	200	61
Carding	200	52
Drawing	200	63
Combing	200	61
Roving	200	81
Spinning	200	83
Winding	200	76
Twisting	200	80
Slashing	750	100
Weaving	750	96
Knitting	500	100
Waste Processing	500	85
Other	500	97

Source: North Carolina Department of Labor, Occupational Safety and Health Division.

cotton dust standard." This average represented approximately 72 percent of workers in cotton preparation and yarn processing and a full 98 percent of workers in cotton weaving and slashing. Centaur found several mills with all departments in compliance and suggested that even a 100 ug/m^3 PEL may be technologically feasible.[82]

The OSHA cotton dust regulation is not only to be technologically feasible, but it has been complied with very quickly. The modernization and use of new technology in textile plants is in large part responsible.

The process of investment decision-making, the role of regulation in that decision, the nature of regulations and their use to spur the development and installation of new technology are all illustrated in the OSHA cotton dust regulation. Regulation may well be an important consideration in an investment decision. It is not likely to be the sole consideration. The most effective investments usually achieve multiple goals, compliance with regulation being but one. A 1980 Commerce Department study[83] found that while U.S. companies through the 1970s were not modernizing as quickly as overseas competitors, that great strides were being made, and that the possibilities were vast. During the last 15 to 20 years, it found that "textile machinery developments have undergone what is described as a technological explosion [which] has virtually swept across all major processing categories."

Some compliance clearly has relied on retrofit, enclosure, and add-on techniques as RTI had suggested in 1976. But a new generation of textile machinery has played an increasingly important role. A 1980 study for NIOSH of "Control Technology Assessment of Raw Cotton Processing Operations" studied various methods being used in the textile industry. Figure 9 examines opening through winding, listing both add-on control

FIGURE (Part A)

INDEX OF CONTROL TECHNIQUES AND PROCESSING VARIABLES

Reproduced from best available copy.

Control Techniques and Process Equipment	Control Techniques 3.1.2 Local Exhaust Ventilation over Opening Hoppers 3.1.3 Local Exhaust Ventilation over Waste Grinder 3.1.7 Enclosure and Exhaust Ventilation of Opening Line Conveyor Feed 3.1.8 Local Exhaust Ventilation of Waste Grinder 3.1.9 Local Exhaust Ventilation of Opening Hoppers and Conveyor Feed 3.1.10 Opening Hopper Local Exhaust Ventilation and Pneumatic Transport System Process Equipment 3.1.1 Automatic Feeding (Bale-o-Matic) 3.1.4 Pneumatic Transport from Opening Hoppers 3.1.5 Automatic Feeding (Bale-o-Matic) 3.1.6 Time Cycle Waste Extractor	Control Techniques 3.2.1 Local Exhaust Ventilation and Process Air Flow in Cleaning Process Equipment 3.2.2 Process Equipment for Cleaning Cotton	Control Techniques 3.3.2 Carding Local Exhaust Ventilation 3.3.3 Local Exhaust Ventilation and Improved High Speed Cards 3.3.4 Local Exhaust Ventilation for High Speed Carding Machines. Process Equipment 3.3.1 Chute Feed System 3.3.5 Automatic Waste Removal

Functional Block Diagram

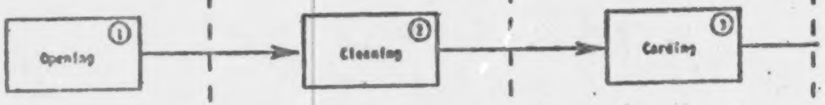


FIGURE (Part B)

INDEX OF CONTROL TECHNIQUES AND PROCESSING VARIABLES

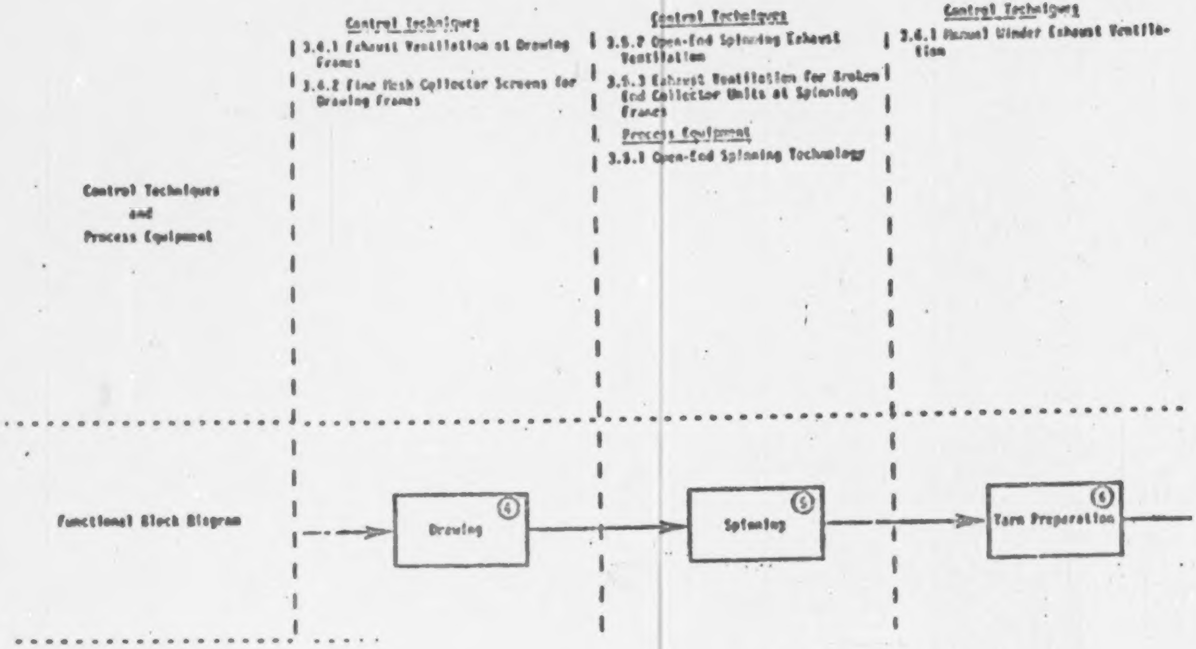
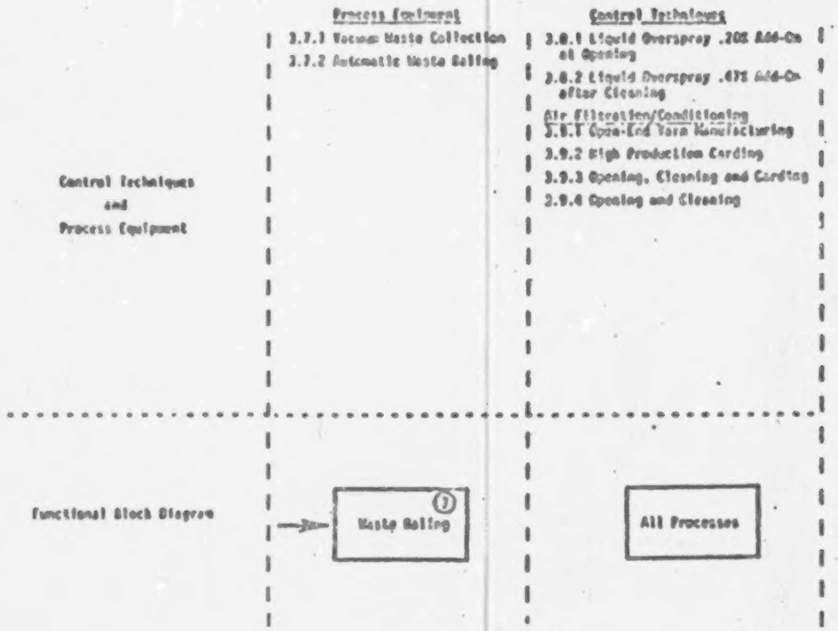

Control Techniques
and
Process Equipment
Control Techniques
3.4.1 Exhaust Ventilation at Drawing Frames
3.4.2 Fine Mesh Collector Screens for Drawing Frames
Control Techniques
3.5.2 Open-End Spinning Exhaust Ventilation
3.5.3 Exhaust Ventilation for Broken End Collector Units at Spinning Frames
Process Equipment
3.5.1 Open-End Spinning Technology
Control Techniques
3.6.1 Manual Winder Exhaust Ventilation
Functional Block Diagram
Drawing
④
Spinning
⑤
Yarn Preparation
⑥

FIGURE (Part C)

INDEX OF CONTROL TECHNIQUES AND PROCESSING VARIABLES


Process Equipment
3.7.1 Vacuum Waste Collection
3.7.2 Automatic Waste Baling
Control Techniques
3.8.1 Liquid Overspray .20% Add-On at Opening
3.8.2 Liquid Overspray .47% Add-On after Cleaning
Air Filtration/Conditioning
3.9.1 Open-End Yarn Manufacturing
3.9.2 High Production Carding
3.9.3 Opening, Cleaning and Carding
2.9.4 Opening and Cleaning
Control Techniques and Process Equipment
Functional Block Diagram
Waste Baling
All Processes

Source: NIOSH, "Control Technology Assessment of Raw Cotton Processing Operations," PB82-186685, June 15, 1980; pp. 1424-44.

techniques and process equipment engineered to incorporate dust control into its production functions. Potential roles for each exist. Process equipment seems to be growing in its use — largely because of its multiple accomplishments.

By 1981, the U.S. purchase of textile machinery was $1.6 billion per year. Modernization accounted for over 70 percent of those expenditures. Shuttleless looms, chute-fed cards, open-end spinning, and other techniques which are currently a major part of the modernization process were well known, if not widely used, in the 1970s. RTI's cost estimates for compliance with OSHA did not recognize the degree to which many expenditures for OSHA compliance would also help to modernize the textile industry — increasing simultaneously yarn and cloth quality, speed and efficiency of production and foreign competitiveness; decreasing downtime, daily manual maintenance, quantity of product seconds, and labor turnover and absenteeism. The only major exception to these achievements is that open-end spinning is not as versatile as ring spinning and may result in yarns of reduced strength.

To ignore the role of technological change in any analysis of the U.S. textile industry is faulty. The textile industry, largely due to its new capital investments, is leading U.S. manufacturing in productivity growth. During the period 1948-1979, textile manufacturing had the highest productivity growth rate of the 19 major manufacturing categories, SIC 20-38. (See Table 7.) At an average annual increase of 4.87 percent, it led chemicals, petroleum refining, and electronic equipment. With a four percent annual increase during the recession of 1981, it is high above the national average of just over two percent. And some mills, Burlington and Cone Mills among them, have, in their annual reports, been

Table 7

Major Manufacturing Categories Ranked According to Productivity Growth Rates, 1948-79

SIC[a] Group No.	Industry Description	Growth Rate (percent)
22	Textile Mill Products	4.87
28	Chemicals and Allied Products	4.40
29	Petroleum Refining and Related Industries	4.21
36	Electrical and Electronic Equipment	4.09
24	Lumber and Wood Products	4.06
371	Motor Vehicles and Equipment	3.88
21	Tobacco Manufactures	3.61
20	Food and Kindred Products	3.05
38	Instruments and Related Products	2.91
23	Apparel and Related Products	2.58
26	Paper and Allied Products	2.56
30	Rubber and Miscellaneous Plastic Products	2.38
372-79	Transportation eq. exc. Motor Vehicles	2.28
31	Leather and Leather Products	2.01
32	Stone, Clay, Glass and Concrete Products	1.97
34	Fabricated Metal Products	1.95
35	Machinery, except Electrical	1.70
25	Furniture and Fixtures	1.70
27	Printing and Publishing	1.64
33	Primary Metal Industries	0.97

---

[a] Standard Industrial Classification.

Source: Machinery & Allied Products Institute, 1982 and U.S. Bureau of Economic Analysis.

boasting six percent average annual increases for several years.

Newly emerging technology in the textile industry can be credited with significant improvements not only in productivity and cloth quality, but in controlling dust emissions as well. The difficult question of course is: how much of a given technological development is a direct result of the pressure of an OSHA regulation, and how much of the technological development is due to other forces? Trying to differentiate, in the textile industry, between technological improvements that are the result of the OSHA cotton dust regulation and technological improvements resulting from other causes is extremely difficult. It cannot be done with total certainty. Many factors have influenced the textile industry to invest the hundreds of millions of dollars into new plants and equipment. For example:

1. In order to compete in the world market, the textile industry needs the newest and latest equipment. It needs to use machinery which achieves faster production speeds, improved cloth quality and lower labor costs. Most believe that it is this issue which has most influenced decisions to invest.
2. The textile industry is second only to the rubber industry in the age of its plant and equipment. Government surveys indicate that 29 percent of U. S. textile machinery is [illegible]0 years old or more. As it is replaced, a new generation of textile machinery is available.
3. As the developing world has increased its textile manufacturing capacity, there has been a growing market, in many instances, for used equipment. This means that if U. S. manufacturers purchase new equipment, they may have potentially high salvage value in their older, fully depreciated, yet functional equipment.

4. Industrial development bonds have become available in many communities which have provided the textile industry with loans for modernization at very favorable rates.
5. The escalating cost of energy, using traditional production methods, has created further incentives to modernize with newer, energy-saving technologies.
6. Regulations of OSHA and EPA required very substantial expenditures for compliance if the method used was retrofit and enclosure. These expenditures would be a diversion of funds from productive capacity. In such a situation, managers would have an incentive to search for equipment changes that would both meet regulatory requirements, as well as to improve productivity.

All the above factors and others as well have been part of the decision making in many plants. Each plant has its own product lines, its own vintage and specification of equipment, its own dust levels and energy consumption levels, etc.

Modernization in the textile industry is proceeding at an unprecedented rate, with one leading analyst explaining that "there has been as much change in the last 10 years as in the 100 years before that." Spokesmen of the U. S. textile industry acknowledge this point. Even in 1977, prior to the promulgation of the OSHA cotton dust standard, Jordan Yale, a textile economic consultant, wrote in Modern Textiles:[84] "Textiles, one of the nation's oldest industries, is undergoing a renaissance that could transform it into one of the leading U. S. industrial sectors. In this vast modernization process, OSHA compliance has come hand in hand with the productivity increases." (See Section IV for details.)

Industry spokesmen admit that it is increasingly difficult to distinguish between investments made for health and safety and for productivity improvements. The most commonly used index is the McGraw Hill Survey, based on expenditure levels for compliance supplied by the companies. In the textile industry, it is hard to know, if at all, whether automatic picking, chute-fed cards, open-end spinning, shuttleless looms, or in fact traveling cleaners, air-conditioning and humidity control expenditures were installed due to regulatory pressure alone or also as part of efforts to improve corporate productivity. And if the investments accomplish a multitude of goals, what percent of the expenditure should be allocated to OSHA compliance? When asked about OSHA compliance costs at a Fieldale Virginia towel plant, in 1980, Fieldcrest's Ken Baggett said he could not even say how much has been spent because new equipment increases productivity, offsetting some of the cost. Another industry spokesman, even though he believes that large amounts of funds have been diverted due to OSHA, readily admits that the dust abatement effort is not purely that, and if a company is going "to fool with the damned machine, they also want to increase quality or" some other aspect of production. Still another industry official explained that his company had been wanting to make new capital investments for some time and that the cotton dust regulation pushed it to make the decision in a more timely fashion. In September 1982, at Congressional hearings before a House Science and Technology Subcommittee, a leading expert on the textile industry and dust control, John C. Lumsden said: "I am quite sure that dust control played a part in the acceptance and use of new processes and equipment, however, the production advantage in going to the new was necessary for acceptance."[85]

Because dust levels tend to be highest at the earlier stages of yarn production, and because the new technology is very effective in solving dust problems in opening and carding, it is investments in these areas that are most likely to be influenced by the OSHA cotton dust rule. In open-end spinning, the machinery requirements for low dust levels probably puts more pressure on investment decisions. In weaving, health and safety benefits (dust and noise) are important, but probably overshadowed largely by substantial productivity gains from the new equipment.

OSHA can be credited with some technology-forcing in the textile industry, especially with speeding up the adoption of some new techniques. But OSHA regulation cannot be credited totally with any of the major productivity improving machine systems. Multiple forces are responsible; OSHA regulation is one factor, but only one.

Chapter IV

Innovative Technologies Employed in the Textile Industry

In four major processes which affect both productivity and dust levels, major innovative technologies are being incorporated into today's cotton textile mills. The first is opening and picking where the installation of automatic equipment in cotton opening rooms is replacing manual feeding. Second is the use of chute-fed cards in the carding process which removes the necessity for manual carding and most manual cleaning. Third, in spinning, is the conversion for some yarns from ring spinning to open-end spinning. Fourth is a shift in weaving from shuttle to shuttleless looms. Air control and automated cleaning equipment have also shown important advances. All these major improvements had existed for at least a decade before promulgation of the OSHA cotton dust rule.

The biggest advantages in these systems involve faster speeds, consolidation of operational processes, reduced labor, and improved cloth quality. There are also advantages in solving dust problems.

Opening and Picking

The major step forward in this part of the plant is the installation of automatic equipment in cotton opening rooms to replace manual feeding. Automatic bale plucking systems have been part of the industry since the mid-1960s. The carousels and automatic feeders used, which pick off of several bales at once, have the following advantages:

a) Faster picking.

b) A more intimate blend of cloth because carousels can pick off of several bales of cotton at once.

c) Bypassing the manual picker and the related backbreaking work.

d) Eliminating some of the dustiest work of the production process.

(See Figures 10, 11, and 12 for a layout diagram and photograph of an automatic system developed by Automatic Material Handling, Inc.)

Local exhaust is also part of modern automatic feeding. (See Figure 13.)

Carding

The use of chute-fed cards encloses the process and removes the necessity for manual carding and for most manual cleaning. The chute-feeding system to the card has existed since the late 1960s. This technique can mean:

a) The elimination of doffing and racking.

b) Elimination of the manual transport of materials to the card room and hanging the material onto cards and later into feed rolls.

c) Improvement in yarn because the automatic process on feed rolls reduces heavy places in the yarn.

d) More than doubling of speeds in some cases with metallic clothed card instead of flexible cards.

e) Improvement in the settings on cards due to roller bearings on cylinder supports because settings can be closer. This leads to more even clothing with closer tolerances.

f) Better integration of fibers resulting in a more uniform and stronger piece of yarn with improved sliver CV and weight variation.

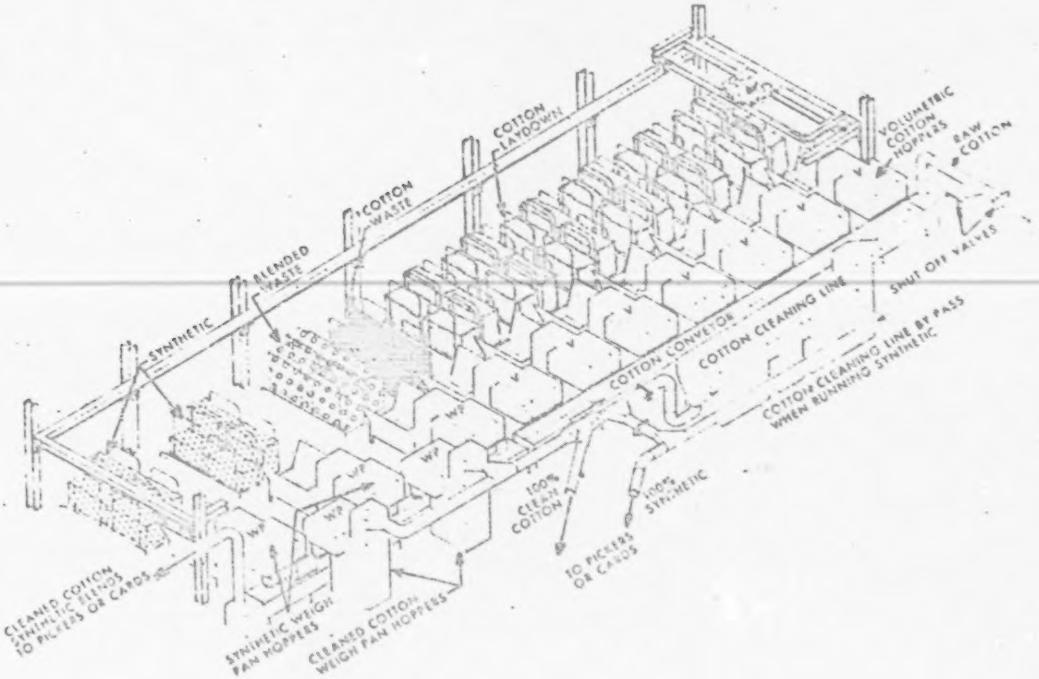
g) Improved spinning performance (due to sliver improvements), meaning fewer ends down.

h) Reduced requirements for floor space.

i) Reduced labor turnover by eliminating undesirable lap laying tasks.

FIGURE 10

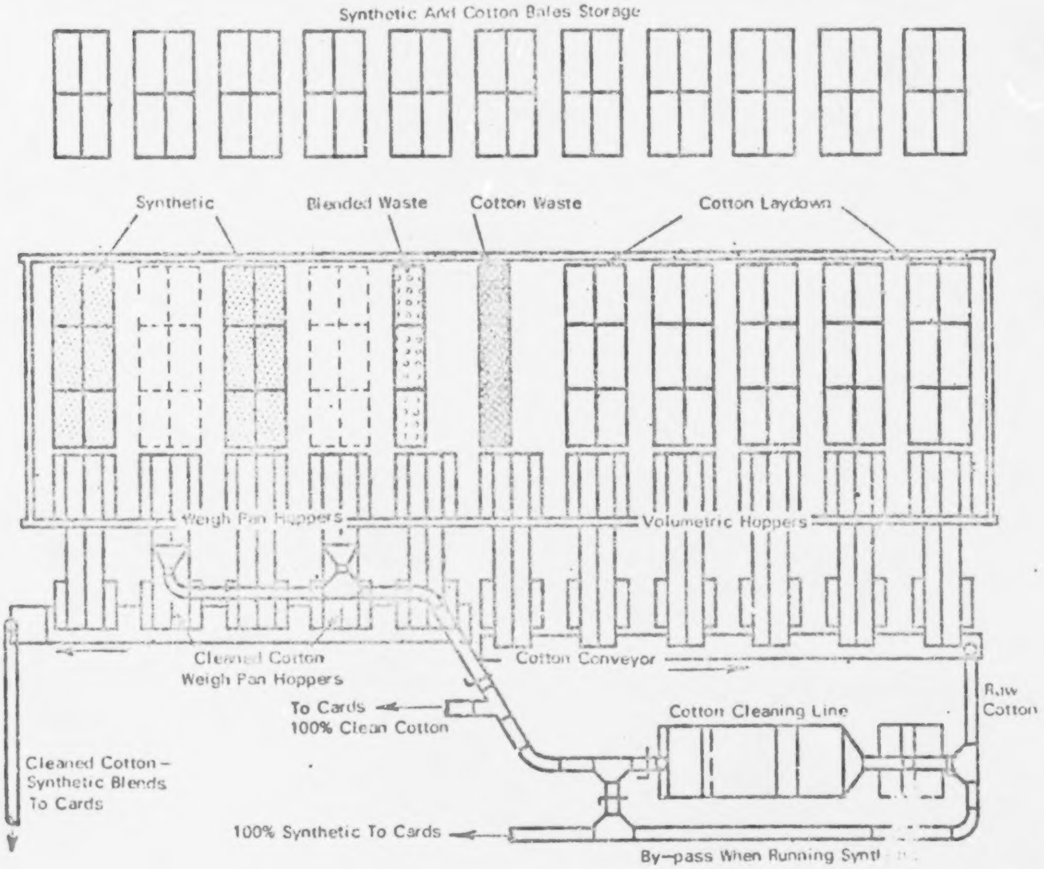
TYPICAL BALE-O-MATIC LAYOUT FOR AUTOMATED COTTON-SYNTHETIC OPENING ROOM BLENDING


COTTON LAYDOWN
COTTON WASTE
BLENDED WASTE
SYNTHETIC
VOLUMETRIC COTTON HOPPERS
RAW COTTON
SHUT OFF VALVES
COTTON CLEANING LINE
COTTON CONVEYOR
COTTON CLEANING LINE BY PASS WHEN RUNNING SYNTHETIC
100% SYNTHETIC
100% CLEAN COTTON
TO PICKERS OR CARDS
CLEANED COTTON SYNTHETIC BLENDS TO PICKERS OR CARDS
SYNTHETIC WEIGH PAN HOPPERS
CLEANED COTTON WEIGH PAN HOPPERS
V
WP

Source: Automatic Material Handling, Inc. "Hidden Facts About Automatic Blending."

FIGURE 11

TYPICAL BALE-O-MATIC TUFT-O-MATIC OPENING ROOM (30 BALE BLEND); COTTON/SYNTHETIC INTIMATE BLENDING LINE; COTTON & SYNTHETIC WASTE AUTOMATICALLY FED


Synthetic And Cotton Bales Storage
Synthetic
Blended Waste
Cotton Waste
Cotton Laydown
Weigh Pan Hoppers
Volumetric Hoppers
Cleaned Cotton
Weigh Pan Hoppers
Cotton Conveyor
Raw Cotton
To Cards
100% Clean Cotton
Cotton Cleaning Line
Cleaned Cotton – Synthetic Blends To Cards
100% Synthetic To Cards
By—pass When Running Synt

Source: Automatic Material Handling, Inc., "Hidden Facts About Automatic Blending."

FIGURE 12
BALE-O-MATIC, AMERICAN MATERIALS HANDLING

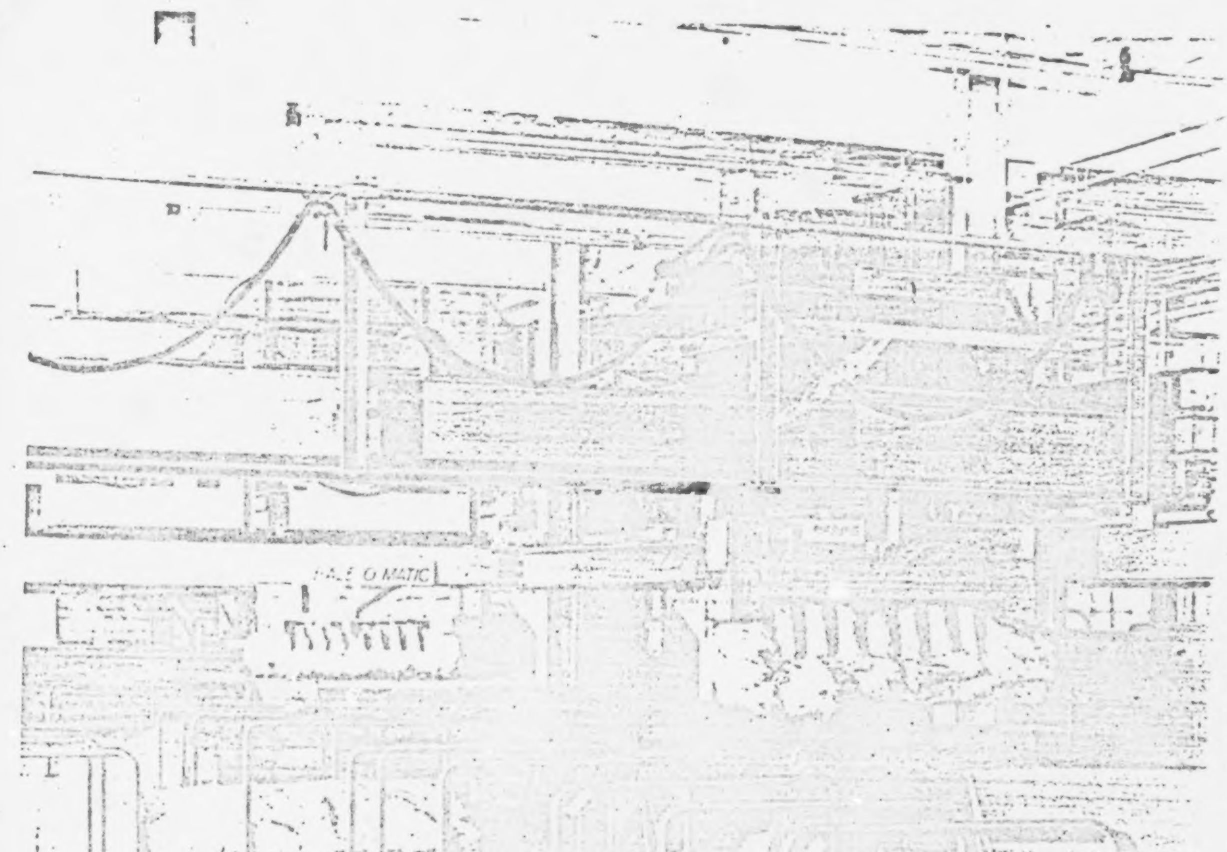
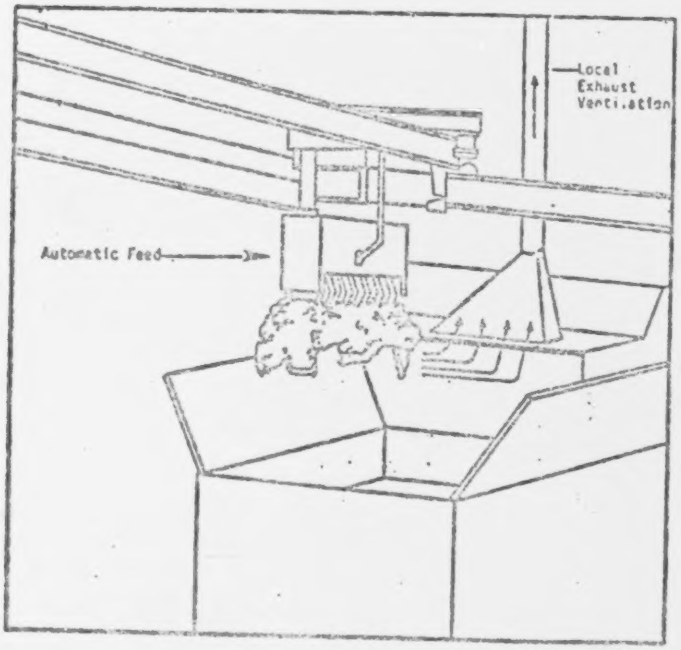

BALE O MATIC

FIGURE 13

HOPPER FEED TABLE - BALE-O-MATIC


Local Exhaust Ventilation
Automatic Feed

Source: Enviro Control, Inc., for NIOSH "Control Technology Assessment of Raw Cotton Processing Operations," June 15, 1980.

j) Reduced dust exposure due to enclosure of cards.

k) Reduced dust exposure because hand cleaning of cards, once done twice a day, can be reduced to once a week.

According to North Carolina Commissioner of Labor John C. Brooks, in North Carolina, in 1982, carding "is now in compliance in most textile operations with the 1984 cotton dust levels."[86] In addition, "local exhaust ventilation is available and used to control cotton dust from the older lap fed cards and the newer chute fed cards."[87]

Spinning

For increasing numbers and types of yarn production, there have been shifts from the conventional ring spinning to open-end spinning. According to a lengthy Department of Commerce study,[88] open-end spinning has been commercially accepted since the mid-1960s. While open-end spinning may never be the preferred method for all spinning operations, where applied, it has been responsible for many improvements:

a) The roving process is eliminated and, in some cases, two drawing processes, breaker and finisher, can be eliminated as well.

b) Some elimination of dust occurs because the process is enclosed. In addition, open-end spinning is more adaptable to the installation of local exhaust ventilation than is ring spinning. Testimony at OSHA hearings in 1977 cited a reduction in one plant from 780 to 170 ug/m^3 when it converted to open-end spinning. Industry reported reductions ranging from 690 to 210 ug/m^3.[89]

In addition, open-end spinning can process a far lower grade of cotton than ring spinning.[90]

According to Omintex, a Czech manufacturing concern with a branch in Charlotte, North Carolina:[91]

> Our spinning equipment in addition to providing increased productivity, provides for lower noise levels and less air contamination by fibers. This is accomplished by spinning in an enclosed chamber under a slight pressure. Our spinning

> equipment also eliminates several processes which can contribute to air contamination. These processes utilize centrifical force in fiber production which can throw loose fibers off into the production environment.

(See Figure 14 for layout of modern production system from blending through spinning.)

Weaving

In weaving, completely new technology began emerging in the mid-1950s. One of the major changes in textile manufacturing equipment currently underway, especially in the U.S., is the shift from shuttle to shutteless looms. Some experts expect that 90 percent of existing mills will have converted to shuttleless looms by 1990. According to International Textile Machinery Shipment Statistics, from 1974 through 1981 alone, over 31,000 shuttleless looms were put in place in the U.S. There are five basic types of shuttleless looms: missile or projectile, flexible rapier, rigid rapier, air jet and water jet. These looms bring many advantages to textile plants. Among them:

a) Productivity with some shuttleless looms is as much as three times what it is with conventional shuttle looms.

b) The cloth can have greater width, speed, marketing and quality advantages.

c) Shuttleless looms are far quieter, bringing noise levels potentially within the OSHA standard.

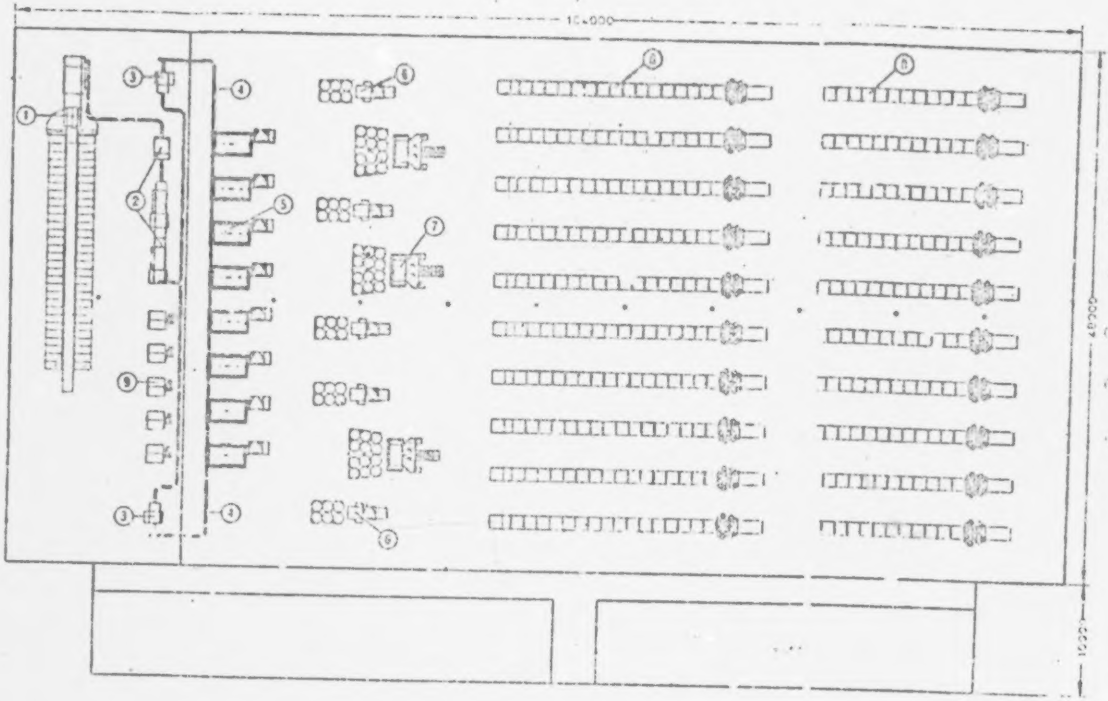
d) Temperature and humidity control, demanded by the sensitivity of the machinery, improve the work environment and the cloth quality.

e) Traveling cleaners on the equipment take care of more dust problems at the source.

(See Figures 15 and 16 for photographs of Leesona Corporation's Shuttleless Aerofil Loom and Omintex's Shuttleless Jettis Loom.)

These technological changes in textile plants during the past few years have changed the process manufacturing of the industry in the

FIGURE 14
THE SUPERCARD IN THE PRODUCTION SYSTEM

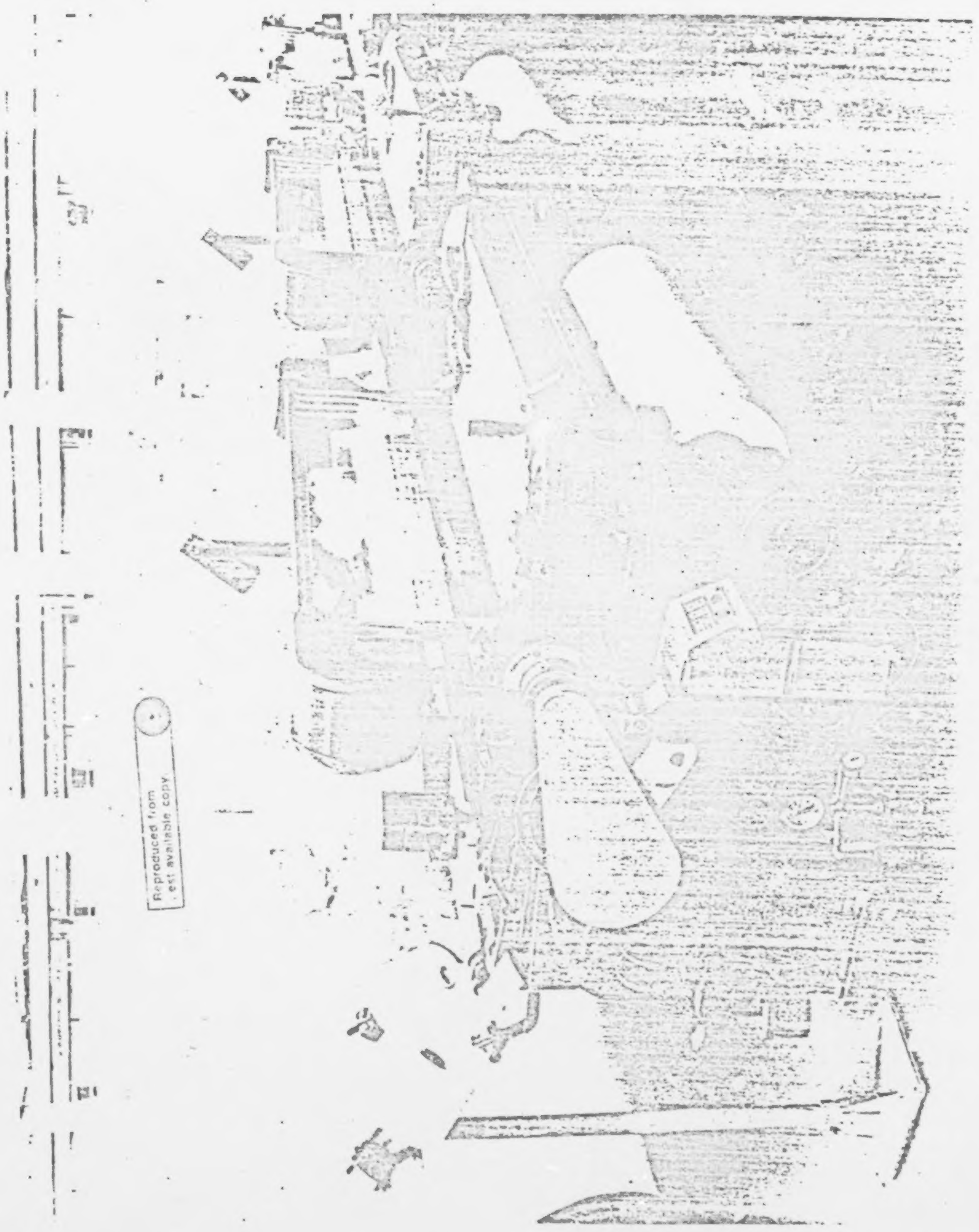


The layout on the left is typical of the space saving arrangement of the Supercard in modern spinning lines. A rotor spinning mill with the following production data is involved:

- ① = Automatic Blending Grab MG 30
- ② = Blowroom line 580 kg/h (1280 lbs/h) cotton
- ③ = Fine opener FO 1
- ④ = Chute feed FL 12
- ⑤ = Supercards KU 12
  260 m/min, 5 g/m,
  70 kg/h (154 lbs/h)
- ⑥ = Autoleveller drawframes RSB 51
  500 m/min, 5g/m,
  135 kg/h (300 lbs/h)
- ⑦ = Two head drawframes SB 52
  500 m/min, 4 g/m,
  209 kg/h (460 lbs/h)
- ⑧ = Rotorspinners RU 11
  87 m/min, Nm 40 (Ne 24),
  216 rotors, 126 g/rotorhour
- ⑨ = Filters for blowroom and supercards

Source: Schubert Salzer "Supercard KU 12"

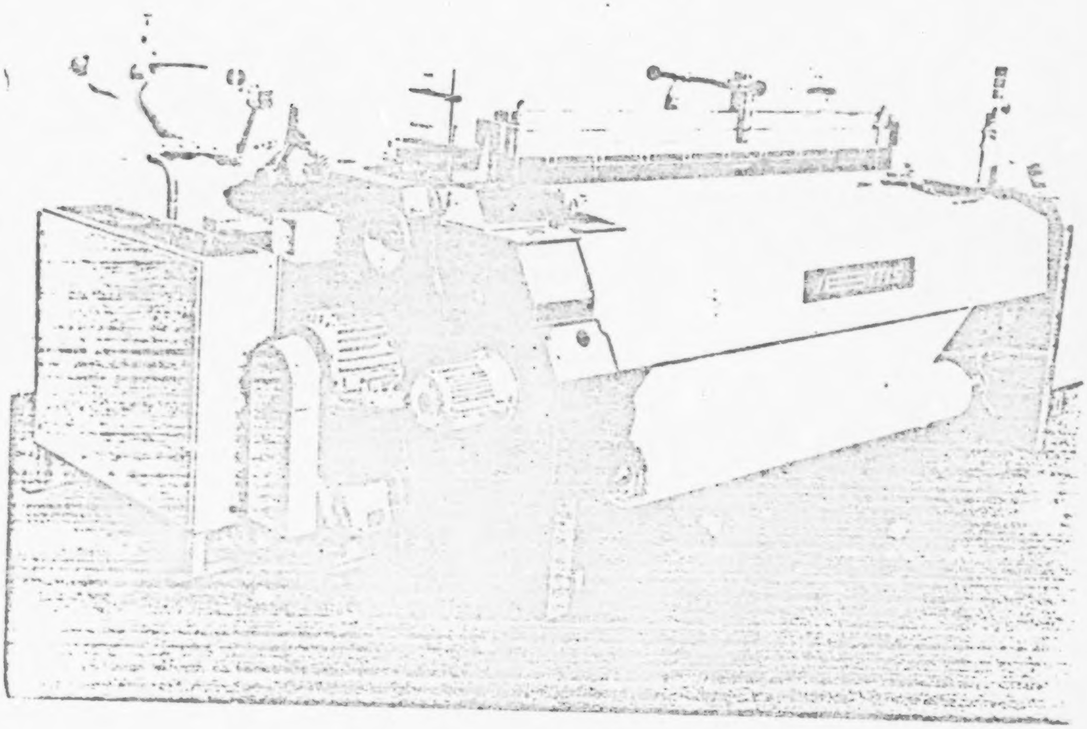
FIGURE 15
AEROFIL LOOM SYSTEM, LEESONA CORPORATION



Reproduced from best available copy.

FIGURE 16

JETTIS LOOM, OMINTEX



following ways:

a) A continuous manufacturing process flow, in place of an intermittent one.

b) A large reduction in the number of processing steps and the number of pieces of equipment, along with a major increase in machinery speed.

c) A gradual shift in job content; from requirements for manual skills to those requiring electro/mechanical skills.

In addition, management efficiency is improving, inventory control is more effective, energy-efficiency has improved substantially and the cotton dust problem is easing significantly.

New technology is also being developed in ventilation and humidity control. One example, apparently unknown at the time the OSHA cotton dust rule was promulgated, is a new method of humidity control which effectively solves many cotton dust problems in the spinning area. During 1979-80, research by Batra, Fornes and Hersh and others[92] found that significant amounts of the particulate matter in the air of textile plants came from the humidification system, not from the cotton being processed. Supplying humidifiers with low-solids water has proved an effective method of compliance.

Some of the dust control in factories is due not only to the OSHA regulation for protecting workers, but also by the sensitivity of new more sophisticated equipment to dust. Lower machine tolerances have led to cotton dust control techniques, ones which often improve productivity as well as increasing the useful life of the equipment. Spinning frame cleaners, which prevent accumulation of lint about the drafting area and on sides of spring frames improve frame efficiency and yarn quality. Roving frame cleaners prevent lint accumulation, an otherwise frequent cause of frame stoppages. The lint generated by modern high speed drawing has brought about the development of automatic travelling cleaners for drawing frames. These cleaners can improve sliver quality and reduce down time for manual cleaning. Avoiding manual cleaning saves workers from dangerous exposure. It also avoids severe production losses since down time is increasingly expensive, with the speed of modern drawing frames at least three times the level of older models. These cleaners have all existed since the 1950s. Open-end spinning has rotors which are very sensitive to micro-dust and require good cleaning equipment. One technological solution, for both open-end and ring spinning is the use of tandem carding. Besides increasing productivity, providing more intimate yarn blends, and being more energy efficient, Crossrol, producer of one tandem carding system, has this to say in its advertising:

> "Reduced dust and micro-dust produces the cleaner sliver essential for troublefree open-end and ring spinning. Reduces dust emission at every step from carding through weaving for easier OSHA compliance."

Another system, this one an air cleaner system, developed during 1980 by Santek, Inc., will not only reduce dust levels, but will also save energy over traditional filtering methods. Santek has an application pending for exclusive licensing on a Wet Wall Electroinertial Precipitator originally developed by the Batelle Research Institute in Columbus, Ohio, but further improved by Santek through the use of pulse power supplies. In consultation with the South Carolina Energy Research Institute,[93] Santek has worked on the use of a Wet Wall Electroinertial Precipitator to remove particles from hot air exhausted by tenter-frames in a textile finishing mill. The technique removes visible particulate from the hot air before it is exhausted to the outdoors and the air can be returned to the plant where the energy can be removed by a heat exchanger or put into an air make up room for use in the plant environment. (See Section V for more detail on energy-saving technology.)

Rebuilt Cards

New technology is also being used to rebuild old equipment. This is different from retrofitting old equipment with ventilation equipment, dust cleaners and other controls. Old machines are remade to operate more efficiently. The major reconstructions are rebuilt cards and techniques to convert conventional shuttle looms to shuttleless looms.

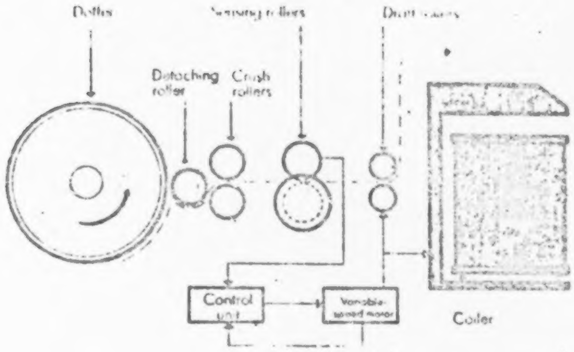
Cards can be completely rebuilt — with cylinder speeds increased, settings improved, etc. Just a few examples are listed below. Walton Mill in Monroe, Georgia installed 32 rebuilt cards along with a chute-feeding system, as part of a $10 million dollar modernization, and according to their president and treasurer, G. Stephen Felker, "It's basically a brand new card room."[94] A yarn mill of Little Cotton Manufacturing Company, which has only 15 cards, rebuilt them and installed autolevellers (See Figure 17 for diagram illustrating the principle of levelling.) in conjunction with a chute-feed system. Carding efficiency increased by 9 percent.[95] Opp and Micolas rebuilt its cards, and used new fronts and autolevelers.[96] Riegel, in its Trion, Georgia modernization, rebuilt its Platt Saco Lowell cards with Crosrol fronts and autolevelers.[97]

Conversion From Shuttle to Shuttleless Looms

For 15 to 25 percent of the cost of a new loom, a company can increase its productivity up to 70 percent by converting its conventional shuttle looms to air-jet looms.[98] Whereas a new loom may cost $30,000-$40,000, converted looms can achieve at least 70 percent and up to 80-85 percent of the speed of new looms at costs of approximately

FIGURE 17

ELECTRONIC LEVELLING SYSTEM


Doffer
Sensing rollers
Draft rollers
Detaching roller
Crush rollers
Control unit
Variable-speed motor
Coiler

Principle of levelling

Source: Schubert Salzer, "Supercard KU 12"

$6,000-$10,000. The system, offered by manufacturers including the U.S. companies Leesona and Draper, and also reduces dust and noise levels.

Leesona's air jet converstion kit was first applied to some of the units at Dan River Plants on an experimental basis.[99] The loom conversion unit shuttle-loom does in fact improve productivity by as much as 70 percent, at 15 to 25 percent the cost of a new loom.[100] Leesona's textile division president, William E. Turner, says Aerofil will run 50 percent quieter and eliminate vibrations. This is accomplished by replacing 450 pounds of oscillating mass with a circular motion.[101]

The Aerofil$^{\text{tm}}$ system converts a Draper X-3, 50-inch loom to shuttleless operation and increases its productivity from 198 to 320 picks per minute. In addition, battery loading and bobbin stripping have been eliminated; hauling of filling has been sharply reduced. Also, precise control of pick length eliminated the need for false selvages, hence saving substantial amounts of yarn.[102]

Draper Corporation in 1982 began mill trials of its conversion kit, hoping for commercial availability at the same time as Leesona. Rights to a West German company's technology have aided the company.[103] Draper sees its development of conversion kits as meeting an immediate need in the industry, but not as being the answer for the long run. According to Draper President William Cordes:[104]

> We see the conversion project as something the industry needs right now, but there are just so many fly shuttle looms in production and we feel that at some point we will need to offer something else to the industry.

Draper's goal is a totally new air jet loom. The main conversion kit being offered is for Draper's own X-3 loom. Conversion takes approximately two weeks, costing about $8,000 for the conversion system and $2,000 to recondition the old loom. Conversion kits for other loom models are being developed.

To what extent could the development of conversion kits be related to OSHA cotton dust regulations? A study by the Department of Treasury[105] studying the influences on development of new textile technology did not find regulation a factor. Instead, they determined that the use of shuttleless conversion kits in the near future would be due to technological and economic obsolescence of existing loom equipment. While it is clear that the shift to shuttleless looms has powerful productivity forces behind it, the fact that work environment improvements are required by law, and in part solved by the new technology, must be considered as an additional factor in favor of timely investment.

Corporate Decisions on Modernization

Cotton mills, large and small, are modernizing. In the process, many have achieved compliance with the OSHA cotton dust rule. With an estimated 80 percent of cotton textile manufacturing processes in compliance nationwide, the figure for modernized mills should be far higher. What follows are some examples of plant modernization that have simultaneously increased productivity and reduced worker exposure to cotton dust.

1. **BURLINGTON INDUSTRIES** the nation's largest textile manufacturer with 64,000 employees, has many modernization schemes underway. As a result of $1.25 billion in capital expenditures, 1975-1981, it has the newest and most efficient plants in the industry. The company has achieved, over that same period, a 6 percent annual increase in productivity.[106] Below are just some examples of the company's modernization activities:

-- Burlington's Smithfield, North Carolina spinning plant has been a leader in cotton dust control. A Platt Saco Lowell chute-feeding system was installed as well as dust removal and cleaning equipment. The plant is in compliance with the OSHA cotton dust standard.[107]

-- An ultramodern denim weaving plant in Erwin, North Carolina, represents a $55 million investment for the land, preparation and new plant. The plant, according to Burlington, is "a technical necessity" if the company is to keep its denim production competitive. Equipment includes wide-width Sulzer shuttleless weaving units, complete climate control, a highly mechanized dust collection system, and computer-controlled energy monitoring.[108]

-- In 1979, Burlington replaced 700 Draper fly shuttle looms in its Shannon, Georgia plant with some 450 Ruti air-jet looms. None of the 1,300 employees were laid off and speeds increased 2 to 3 times.

-- The Vinton, Virginia weaving plant converted to shuttleless weaving in 1981 as part of a $25 million modernization program. Its 600 employee workforce was fully maintained.[109]

-- Burlington is modernizing, for March 1983 completion, two of its sportswear fabric corduroy operations at a cost of $25 million. Its current Asheville, North Carolina Plant will convert from shuttle to shuttleless weaving, using wider and faster looms. With this conversion, Burlington will have converted all its looms to shuttleless.[110]

2. **CANNON MILLS** this year bought two lines of Feed-O-Matic chutes from Automatic Materials Handling. The 16 chutes will run at over 140 lbs/hr.

with double coiler and will feed from two 60 inch fine openers and blending reserves.[111]

3. **CLINTON MILLS** began shuttleless weaving with more than 200 Sulzer looms in 1978 in its Geneva, Alabama plant. During 1981, more than 100 additional Sulzer looms were purchased making the plant totally shuttleless. It purchased automatic winders equipped with yarn cleaners. And these operations in turn required high quality yarn preparation, beginning with opening. Width was increased and the speed of cloth production and cloth quality as well.[112]

4. **CONE MILLS**, despite decreases in sales, income and working capital for 1981 over 1980, boasts that "the company's aggressive modernization program has produced large gains in productivity of as much as 6 percent per year over the past 3 years."[113]

One important example predates the current OSHA cotton dust standard. In 1975, Cone ordered projectile shuttleless weaving machines from Sulzer for its Cliffside, North Carolina plant.[114]

5. **DAN RIVER** this year has a $30 million capital expenditure program, mostly for Sulzer rapier looms.

6. **FIELDCREST MILLS**, modernizing its Fieldale, Virginia towel plant achieved increased productivity and promises OSHA compliance at a 1984 level, by 1982.[115] The plant has a new chute-feed system. Production increased from 20 lbs/hr. to 100 lbs/hr.

Fieldcrest's Columbus towel plant also was modernized, with production reaching 125 lbs/hr. The plant will also have the latest automatic opening equipment as well as effective cotton dust control measures.

7. **GREENWOOD MILLS** in 1981 ordered blending machinery consisting of 11

lines of weighpan feeders conveyors, high value opening blenders and distribution system for its #2 plant in Greenwood, South Carolina.116 The year before it bought 8 versamatic drawing frames for its #5 plant and new roving frames for its #14 plant.117

8. **HABERSHAM MILLS** in Georgia, a subsidiary of the Russell Corporation, installed Truetzler chute-feeding in 1978, along with AMH automatic opening and Bahnson under-card cleaning. New drawing and roving equipment was installed in 1979. Quality has been increased and the card cleaning system returns waste to an automatic baler.118

9. **HARMONY GROVE MILLS** in Commerce, Georgia invested in a chute-feed system and increased its versality. It also improved its sliver weight variation from 10-12 grains/yard to ± 1.5 grains/yard. Cleanliness improved and spinning ends down dropped. Automatic opening as well as Pneumafil cleaners from opening through roving are used. Waste collection is centralized.119

10. **INMAN MILLS**, in expanding its Ramey Plan in Encree, South Carolina, added 380 new Picanol PGW rapier shuttleless looms to the 120 already in place there.120 The company has replaced all of its ring spinning with open-end spinning.121

11. **LINN-CORRIHER CORPORATION** spent $3 million on modernization. By replacing 40 to 50 year old equipment, it increased its efficiency and came into OSHA compliance in all but its waste room.122

12. **LITTLE COTTON MANUFACTURING COMPANY'S** Homer Yarn Mills in South Carolina is a small plant with only 15 cards. Carding efficiency was increased by nine percent with the installation of a chute-feed system. Significant improvements were made in weight variation at drawing, roving and spinning. Card waste was reduced 70 percent and OSHA compliance was

achieved.[123]

13. **M. LOWENSTEIN CORPORATION'S** 1981 modernization program was double its 1980 size, at $21.5 million. The funds, to be used for new plant construction, loom purchases and energy-related equipment are expected to come from available cash and 1981 cash flow.[124] Among its purchases were 11 Platt Saco Lowell combers for its Pacific Columbia Mills' Olympia Plant in Columbia, South Carolina.

14. **MARTHA MILLS'** Thomaston, Georgia plant (a subsidiary of B.F. Goodrich,) experienced improved quality and a halving of card waste by installing chute feeding and other card room improvements. Weight variation has beenreduced and the yarn has a much cleaner appearance. New drawing and roving equipment as well as provisions for filter reclamation were also installed.[125]

15. **OPP AND MICOLAS MILLS** of Opp, Alabama, a division of Johnston Industries, is saving $250,000 a year since installing a chute feed system. The installation at Micolas allowed the plant to replace 111 cards with 60, increase production from 30 lbs/hr. to 55 lbs/hr and boost total poundage output. Installation at Opp brought similar production increases and the plant replaced 92 cards with only 50. Absenteeism and turnover were reduced. Savings were achieved in labor, supply costs and waste. These improvements, along with Pneumafil card cleaning equipment allows both plants to meet the OSHA dust standard.[126]

16. **RIEGEL'S** 1981 capital expenditures of $25.7 were a new record for the company, but scheduled 1982 expenditures rose even further to $30 million, in order to "continue to provide the most competitive equipment and technology." Expenditures in 1981 were over 80 percent for modernization, over 12 percent for expansion and only 1 percent for environmental

needs.[127] Investments in 1981 included several million dollars in its Woodruff, South Carolina plant on Rieter open-end equipment as well as Unifloc opening and Rieter chute feeding cards and drawing equipment.[128] At its Trion, Georgia plant in 1982, Riegel added 12 open-end spinning machines, as well as AMH Bale-O-Matic stockfeeding and 145 Rieter chutes feeding rebuilt Platt Saco Lowell cards. Trion also bought 400 Sulzer shuttleless weaving machines.[129] Card efficiency increased 9 percent. The indigo denim mill cut annual card-tender labor turnover from 100 percent to 10 percent.[130]

One Riegel modernization program of interest, predated the current OSHA standard, but was promoted by the previous OSHA rule, and perhaps by knowledge of the pending one as well. In July 1977, South Carolina OSHA cited Riegel's 700-employee Greenwood County Ware Shoals plant for cotton dust violations in the wastehouse and in the card room. In August 1977, Riegel told OSHA of its intention to spend $5 million for a new air filtration system and new card room equipment. In 1979, OSHA inspectors found the plant in compliance and Riegel Board Chairman, Robert Coleman, said:[131]

> "Nobody with common sense can argue that it isn't beneficial to clean up a workplace...it's...money well spent regardless of whether we meet the OSHA standard or not. It provides a more attractive workplace, and that allows us to attract workers more easily in a labor market that's getting increasingly tighter."

17. **SPRINGS INDUSTRIES**, the only U. S. textile manufacturer according to the Value Line Industry Survey expected to outpace the stock market in 1982, said in its 1981 Annual Report:

> Over the last several years, we have increased productivity while improving the work environment in our plants. We are installing new machinery that enables Springs' people to produce greater volume per person, and we are phasing out obsolete facilities. New high-speed machines in one plant are

> three times as productive as the machines they replaced...In another plant area, new shuttleless looms are more than twice as productive as the conventional shuttle looms they replaced...Modernization of yarn manufacturing resulted in better quality yarn, improved weaving efficiency and a higher percentage of first quality cloth. Over the last several years, we have increased productivity while improving the work environments in our plants.

At its turn-of-the-century Lancaster plant, old buildings are being outfitted with air-jet shuttleless looms and computer monitoring systems. At its Frances plant in Fort Lawn, South Carolina, even before the current OSHA standard, in 1977, Springs' use of a chute-feed system was saving $45,000 per year in labor costs. Carding output increased 10 percent even though total cards fell from 36 to 24. The plant achieved evener motions at card fronts, thus maintaining sliver weight levels within close tolerances. Quality improved throughout the plant. Thick-thin places and chokes were eliminated and dust was controlled.[132]

18. **STEVENS COMPANY** is the second largest U. S. textile manufacturer, with capital spending in 1981 of $90 million, and an OSHA compliance level for 1984 requirements of 87 percent in its cotton processing areas.[133] The company expects to spend $100 million or more on capital investments throughout the 1980s "in order to ensure that ...manufacturing facilities are as efficient as possible."[134]

In Chester County, South Carolina, with the help of $10 million of industrial revenue bonds, Stevens financed high speed looms for its 3 Republic plants, employing 15,000 people.

19. **UNION UNDERWEAR** in 1979 installed chute-feed systems in its Jacksonville, Alabama yarn plant and reduced labor costs, improved quality and efficiency and made significant improvements in absenteeism and labor turnover. Dust was controlled.[135]

20. **WALTON MILLS, INC.** spent $10 million over four years on modernization -- installing new equipment in its opening, carding and spinning

operations. Being installed were 80 Saurer rapier shuttleless weaving machines as well as 3 Ingolstadt open-ending spinning machines. According to the Daily News Record, of September 7, 1982, approximately 70 percent was spent because of investment incentives provided by the 1981 Capital Recovery Act. Looms are computerized with an automatic overhead loom cleaning system, cards have been rebuilt, and opening uses Bale-O-Matic. OSHA compliance was also achieved.

The U.S. Textile Machinery Industry Is Moving More Slowly Than the Textile Industry

The large strides in modernization, productivity improvements, and designed-in engineering controls for cotton dust can be credited mostly to technology imported from overseas. In 1981, the U. S. textile industry, which is the largest single world textile machinery market, spent $1.6 billion on plants and equipment. These amounts are continuing to grow. Over 70 percent of that amount is for modernization.[136]

Half of the $1.6 billion is being spent in the U.S., largely for parts, materials handling equipment and less sophisticated machinery. The other half, for the high technology textile systems is coming largely from West Germany, Switzerland, Italy, France, Japan and Great Britain. Between 1962 and 1972 alone the value of foreign textile machinery sold in the U.S. increased by 1278 percent -- from $39 million to $497 million.[137]

The U. S. textile machinery sector of the economy (S.I.C. 3552) is losing ground -- not only in the $1.6 billion annual U. S. market, but also in the $7.1 billion world market. Of the 600 U. S. textile machinery firms, only about 25 percent of them make complete machines.[138] Parts and accessories account for approximately 40 percent of industry sales.[139] Whereas, U. S. textile machinery manufacturers, in 1960, supplied 93.4

percent of the domestic market, by 1979 the figure had dropped precipitously to 54.5 percent, and much of this share was in parts rather than new complete machines. (See Table 8.) In the world market, over the period 1960-1979, the U. S. share fell from 15.5 percent to 6.6 percent.

An equally alarming figure is the very high value of U.S. spare parts business as a percentage of its international sales. While the figure is only 27 percent for Italy, 49 percent for West Germany and 51 percent for Great Britain, it is 92 percent for the U. S.[140] Nearly all U.S. exports of textile machinery are spare parts for previously purchased equipment. This points to past U.S. machinery successes, but bodes ill for current and near-future markets, especially for complete machines. U.S. technology is most behind in projectile and jet shuttleless weaving, open-end spinning, high speed winding and knitting equipment.[141] Most new complete textile machinery for open-end spinning and for shuttleless weaving is currently imported.

Overseas machinery manufacturers are establishing bases in the U.S. through acquisitions, joint ventures and the creation of wholly-owned subsidiaries. They are also establishing service facilities. Murata of America (a Japanese firm) has headquarters in Charlotte, as do Omintex (Czech), Toyoda (Japanese) and Nissan (Japanese). Sulzer (Swiss), Pignone (Italian) and Hargeth (German) have offices in Spartansburg, South Carolina. Platt Saco Lowell (British) is in Greenville. In mid-1980, Platt Saco Lowell boasted an order backlog of 9 months to a year on most of its product lines.[142] The Sulzer Group in 1980 had order intake for weaving and knitting equipment of over $430 million, a large increase over the previous year.[143] The joint efforts of Schubert and Salzer Machine Works with Ingolstadt, West Germany reported record sales for 1980.144

Table 8

Textile Machinery Sales by U. S. Companies

	% of U. S. Market	% of World Market
1960	94.3%	15.5%
1970	67.1	9.9
1979	54.5	6.6

Source: U. S. Department of Commerce, "Opportunities and Strategies for U.S. Textile Machinery Manufacurers to Improve Their Competitive Positions in Domestic and Foreign Textile Markets, 1980-1985," September 1980, p. I-33.

Some U.S. companies are also experiencing growth. In early 1980, Automatic Material Handling announced orders of $2.5 million to two U.S. companies for 12 Bale-O-Matics and new hoppers. Another textile manufacturer bought 21 chutes from them and substantial purchases were made by French companies.[145] Leesona, Draper, and others -- including many air control equipment companies — are also increasing their sales both at home and abroad.

According to expert industry analyst, T. J. Jackson in the U.S. Department of Commerce,[146] U. S. manufacturers are not expected in the next five years to regain the technological advantage they once had in winding and weaving, but they may stay competitive in support equipment and in equipment used in opening through ring spinning (where ring spinning is used). Beyond five years, when even newer of textile equipment is expected, which will further increase productivity, safety and energy conservation, the U.S. manufacturers will face a difficult but important challenge. The technological and economic results from this challenge remain to be seen.

The Textile Industry in Transition

A lot is happening in the textile industry. Plants are closing and plants are being built. Technology is changing at a very rapid rate and foreign competition is challenging the U.S. market with extremely high levels of imports. Most analysts have predicted a slow 1982, but a much rosier picture for the future.

The U.S.-wide recession especially with recent high interest rates has clearly slowed down planned investments in all fields. But the future for the textile industry is optimistic. Value Line Industry Survey says, "we expect the fortunes of the textile industry to change soon..."147

implying that the pressures of the recession and foreign competition would likely be beaten back.

Modernization plans abound. New annual capital expenditures in weaving mills from 1970 1980 alone increased by more than 195 percent from $73.7 million to $217.5 million. Companies realize that they must modernize to survive. According to one company: "The textile industry is shifting rapidly to a capital-intensive one, and new technology is making possible significant gains in productivity."[148]

Stevens alone, for example, expects to spend $500 million for new plants and machinery over the next several years.[149] But Stevens is not only building, it is closing plants as well. Textile Week, June 22, 1981 reported that Stevens was likely to close another 3 or 4 plants on top of the 4 closings or phaseouts already announced, in addition to the purchase 450 new air-jet looms. Because the company is also modernizing, it gets more output from fewer plants and fewer people. Burlington Industries has closed a number of old plants in the past few years, but has also built several new multi-million dollar facilities. Dan River, while committed to an aggressive modernization, has sold off a plant in Simpsonville, South Carolina, and closed its texturing operation in Mebane, North Carolina.

John Tritsch of the American Textile Manufacturers Institute believes that most of the plant closings and consolidations have now occurred; that the transition is nearing some sort of completion.[150] There is some evidence of the transition ending. For example, loom width is increasing, which allows companies greater versality in serving their customers. It also permits many seamless products when narrower cloth does not have to be pieced together. Also, on wider machines, multiple products can be produced simultaneously, such as 3 or 5 towels in a width instead of one. Shifts to wider machines began slowly until there were enough wide weaving machines to justify the expenditure. But according to Textile Industries,[151] the shift is now an accomplishment and firms don't hestitate about acknowledging the trend.

What are the causes of the changes in the textile industry? Is regulation a possible cause for technological progress or is technological progress simply a convenient way to achieve regulatory compliance? Certainly the latter is true, technological progress has been a convenient way to achieve regulatory compliance. According to one expert:[152]

> Much of the production machinery now in use is quite old and was originally designed with little consideration for dust emission. By going to new equipment with controls, there is a likelihood that some or all of the costs of control could be recovered.

But the former may also be true, i.e., that regulation has already caused some of the technological progress that has accurred in the textile industry. But, it is not possible to measure the precise extent to which OSHA's cotton dust regulation has contributed to the degree or speed of change in the industry. It is probably fair to conclude that the productivity improvements in the new equipment, coupled with the serious need to regain a competitive stance in the world market were the primary motivations. But quest for economic renaissance was not sufficient to thrust the U.S. auto or steel industry into an aggressive modernization program. Beyond OSHA compliance, the textile industry had the added benefit of technology which would make not only the economics of the product but also the product itself more competitive.

Many textile mills would have modernized without an OSHA cotton dust rule, and some work environment improvements would have accompanied those new investments. Many mills would not have modernized as quickly, and few would have incorporated as much control technology as they did without the OSHA rule. Health and safety improvements after modernization would have been far more expensive than incorporating controls into new investments.

The industry is complying more rapidly and more cheaply because it is amidst modernization. Modernization is more timely because of the additional push given by legal requirements for the control of cotton dust. All existing data corroborate a relationship between the two.

Chapter V

Productivity and Other Improvements in the Textile Industry

Besides substantially solving the cotton dust problem, and thereby improving the health of tens of thousands of U.S. textile workers, new textile technology has brought several other important changes to the industry. Significantly increased machine speeds, machine versatility and product quality as well as improvments in energy efficiency, production efficiency (through both economic and technological consolidation), and the work environment have resulted. The major innovations which have increased productivity are high speed cards, continuous spinning frames and shuttleless looms.

Older slow cards are being replaced by high-speed cards. Chute-feed systems eliminate doffing, racking, manual transport to the card room and hanging the lap. Open-end spinning eliminates drawing and roving. Conventional shuttle looms are being replaced by very high speed shuttleless looms, some of them ten times more productive than the equipment they replace. Slower manual cleaning of equipment is being replaced by faster automated cleaning equipment. The production process is becoming much more efficient.

In most cases yarns are stronger, cleaner and more uniform. Cloth is of higher overall quality. New fasterlooms can produce wider cloth, giving the manufacturer improved options on sales and further processing, not to speak of the increased amount of fabric that can be produced at one time.

Modernization for productivity and investment for dust control go hand in hand. Testifying before a House of Representatives Subcommittee on Science and Technology, in September 1982, a spokesperson for the

American Textile Machinery Association said:[153]

> In order to assure compliance, it requires an investment in both new production machinery and dust control equipment. Compliance is very capital intensive...

The heavy investment in new technology has paid off, and not just in limiting worker exposure to cotton dust. The industry as a whole has made the tough decision to invest in capital-intensive improvements and over the past several years, textiles has led the U.S. manufacturing sector in productivity improvements. (See Section III.)

Energy Savings

Energy savings have also been a benefit of new textile machinery. From 1972 to 1980 alone, the textile industry "improved its per unit energy efficiency by over 17 percent through the use of known technology and energy management programs."[154] Researchers have concluded that best available technology could yield energy savings of another 15 to 30 percent over current energy efficiencies.[155]

Mr. T. J. Jackson, textile machinery analyst for the U.S. Department of Commerce, as well as analysts for the American Textile Manufacturers Institute, assert that the textile industry, in recent years, has been successful in achieving a 15-17 percent energy savings in its finishing plants.

The most promising candidate for energy savings is the air-jet loom, one of the popular types of shuttleless looms. Reduced air consumption can be achieved by a new heat and water recovery process. And, in addition to saving energy and water, there is also a reduction in the quantity of polluted effluent which assists companies with their EPA compliance efforts. Draper as an air-jet conversion system which saves energy. The Draper loom uses an electronic system so that when the loom is stopped, the air jet valves close, thus avoiding the loss of air consumption. Platt Saco Lowell in 1980 exhibited sizing equipment in which energy requirements were 85 percent less than those of other machines.[156] Sulzer advertises that its PS and PU weaving machines have reduced energy consumption. Sulzer says that these savings are due to techniques which reduce machine stress and to using computers for optimizing machine motions and weft insertion.

New carding technology, which increases the speed of production and reduces cotton dust exposure, can reduce energy requirements as well. In 1977, at OSHA rulemaking hearings, testimony by Parker Reist, Lawrence Kornreich and David Bolda from the University of North Carolina, asserted that:

> ...replacement of older, slower cards by higher-speed units will increase production without additional volume requirements, or conversely, the same production rate can be maintained with signficantly smaller air flows needed.

The U.S. Industrial Outlook for 1982 states that a new generation of textile machinery equipment, which will reach world markets in 1987 and beyond, will show further improvements in energy conservation.

Improvement in Product Quality

New textile machinery, while achieving dust control, also is responsible for improving the quality of the textile product. The President of Walton Mill in Monroe, Georgia, nearing the end of a four-year, $10 million modernization program which includes new equipment in opening, carding, spinning and weaving says "the new machinery should meet current government regulations and should produce better quality yarn and fabrics."[157]

Quality improvements begin with new equipment for opening and picking. Because of carousels and automatic feeders, picking can be from a larger number of bales, thus achieving a better blend of cotton. The Bale-O-Matic of the Automatic Material Handling Company claims improved yarn quality due to "consistent hopper feedings [and] controlled cotton mix."

New carding technology also adds to quality. Settings on new and rebuilt cards can be improved, and roller bearings on cylinder supports allow closer settings. Also because the clothing is more even and metallic clothing allows tighter settings, one can achieve a better integration of fibers. This produces a more uniform and stronger piece of yarn. There are also fewer broken threads.

The U.S. Department of Commerce, in studying the chute-feeding system, found that quality improvements came from eliminating thick lap/joints and also from less reliance on judgment and more on automation.[158]

Martha Mills in Thomaston, Georgia, claims that its chute system, Levelfeed, CMC, improves yarn quality by contributing to reduced weight variation.[159]

New spinning technology improves yarn quality. New self-cleaning mechanisms in open-end spinning keep small rollers from getting dirty quickly and thus add to increased yarn quality. Springs Industries claims that "modernization of yarn manufacturing machinery resulted in better quality yarn....and a higher percentage of first quality cloth."[160] An Italian fiber manufacturer that uses robots in its spinning systems claims increased yarn quality due to less handling.[161]

New weaving technology is also improving product quality. Textile Industries recently published an analysis of shuttleless looms, finding substantial improvements over conventional shuttle looms:[162]

> "A comparison of quality with similar fabrics woven on fly-shuttle looms shows shuttleless weaving to be superior in all categories. Improved quality results in dramatic increase in first-quality, woven cut lengths, generally providing lengths which are more than double those obtained from fly-shuttle weaving."

Draper's air jet conversion loom claims higher quality cloth due to a mechanism that removes bad picks and thus minimizes the defects in the cloth. Dornier's rapier weaving machine as well as other shuttless weaving systems has special motions to ensure perfectly woven, closed selvedges. Dornier's rapier weaving machine also has reverse motion capability which allows it to repair broken picks at any phase, without starting marks. Sulzer also boasts of its firm selvedges with its PS and PU weaving machines. Because of repair of broken threads, the proportion of first-quality cloth is increased. And, uniform weft tension adds to quality.

Humidity control and mechanical cleaning systems which remove excess lint also increase product quality.

Increases in Recycling and Capture of Resalable Byproducts

Platt Saco Lowell's new non-aqueous sizing system eliminates health, safety and pollution problems by evaporating the necessary solvent, condensing, and then recycling it.

Martha Mills in Thomaston, Georgia, has purchased new fiber-reclamation equipment which it believes contributes even more toward reducing card waste than its new chute system.[163]

Habersham Mills, also in Georgia, has installed a card-cleaning system which returns waste to an automatic baler.[164]

Reduction in Needed Floor Space

As the textile industry has consolidated its production process, some steps have been eliminated, thus saving necessary floor area. In other cases, the machines themselves are more compact. This may mean reduced costs in building new facilities and may allow for less costly expansion in older mills.

The chute-feeding system saves floor space by eliminating picker floor area, lap storage and the lap conveyer systems.

The Picanol Air-tronic weaving claims that "it requires less floor space than any other loom with comparable equipment on the market today."

The Platt Saco Lowell sizing system is designed to use less floor space.

Sulzer says that the compact design of its PS weaving machine, in particular with the warp beam as far inside the machine as possible, not only saves space, but reduces vibration as well.

Reduced Noise and Vibration

Open-end spinning equipment is quieter than conventional equipment; so too are both air jet and water jet looms. Draper's air jet conversion looms are also quieter, and the company expects them to meet the OSHA 90 dBA standard. Dornier advertises its rapier weaving machine as having a "surprisingly low noise level." Picanol claims its weaving machine has a "reduced noise level and vibration-free running." Sulzer says of its PS loom that "optimization of the individual cams has secured good vibration behavior...and noise level." About its PU weaving machine, Sulzer claims "low noise and vibration thanks to precision engineering and computer-optimized parts." Sulzer also credits its R&D efforts with techniques to reduce noise levels despite higher loom speeds.

Reduction in Turnover Costs

A 1983 study for OSHA directly attributes the cotton dust standard with reducing turnover costs.[165] Since the issuance of the standard, Centaur Associates estimated that by reducing turnover costs textile companies had saved $3.7 million.[166] And, it is noted, this $3.7 million (based on an assumed two-week salary for training new employees) could really be very conservative with the actual savings amounting to as much as $18.5 million.[167]

Chapter VI

Summary of Impacts of Cotton Dust Regulation and of New Control Technologies

Economic Impacts

The U.S. textile industry, in large measure due to the installation of new technology, leads the U.S. manufacturing sector in productivity growth. The current problems of 1981 and 1982 are due primarily to recession in the U.S. economy, to high interest rates and to stiff foreign competition.[168] Most experts consider these problems serious but also believe that they have only caused the pace of plant modernization activities to be delayed. Prospects for the textile industry to prosper in the near future are considered bright, mostly because of new technology.

Large and medium-size companies are well on their way to modernization. Small companies may have a tougher problem of making the transition from a highly labor-intensive to a highly capital-intensive production process. But a recent study for OSHA reported that "there are not believed to be major economies of scale associated with ...capital costs per unit of textile output."[169] Acquisitions and mergers face many companies. Plant closings are also occurring. While the number of textile plants and firms declined 10 percent between 1977 and 1982, a major study for OSHA in 1983 found that "these closures appear to be an extension of a long term trend and not a result of the 1978 cotton dust standard."[170]

The pressure for capitalization is not primarily for cotton dust control technology, but rather for productivity and product quality improvements. Control technology leading to OSHA compliance, where incorporated into overall plant modernization, very often has contributed to productivity, product quality and work environment improvements simultaneously.

Has There Been a Shift to Synthetics?

Some compliance may have been achieved not through control of cotton dust, but rather from a shift out of cotton products and into synthetics and synthetic cotton blends. The National Cotton Council complains that "many...workplaces were brought into compliance through blending synthetics with cotton."[171] Experts at the American Textile Manufacturers Institute say that many companies will continue to shift toward greater use of synthetics if they have problems with OSHA compliance. Dr. Carl Dyer, a textile economist at North Carolina State University, has suggested that companies could restrict cotton processing to plants with the most efficient air filtration equipment, and process synthetic materials which product no harmful dust in less efficient plants.[172] And, in fact, during May 1977 hearings on cotton dust, James Chapman, Jr., President and Treasurer of Inman Mills, said, "Inman employees exposure to cotton dust has been decreased by simply substituting synthetic fibers for cotton.[173]

Textile manufacturers and expert analysts, however, also say that the no-iron market and the desire for strong cloth have been responsible for much of the shift to synthetics and synthetic blends. It may be, especially with products like bedding and shirts where consumers want their products to "breathe," that the extent of any shift has already occurred. Mr. James Horwell, Jr., Senior Market Analyst for the National Cotton Council, suggests that the dust standard had an initial impact on a shift to synthetics, but that a reversal may now be occuring:[174]

> "...one of the main reasons given for a trend to higher man-made fiber content blends in sheets and pillowcases has been the dust standard. Other markets have experienced similar reasons. Countering this, of course, is consumer

> demand for more natural fiber. Domestic mills apparently have been reluctant to react to this trend and the cotton dust standard has been given as a reason. Some domestic mills now are reacting.

Domestic consumption of cotton, which fell nearly 20 percent from the onset of the cotton dust standard in 1976 to the present, is expected to rise nearly 6 percent next year. (See Table 9.) One reason for this possible new reaction back toward cotton is that the dust problem can be solved through control technology.

A 1983 study for OSHA minimized the relationship between the OSHA regulation and shifts toward synthetics. It found that "the substitution of synthetic yarns or imports in response to the cotton dust standard is believed to be of minimum concern.[175] Again one has an example of multiple potential causes for a production change in the textile industry. OSHA cotton dust regulations played a role in this transition.

Overall Impacts Most Dependent on Methods of Compliance and Timing of Investments

The question of economic impact is a difficult one. Those firms which relied on retrofit, enclosure and add-on controls clearly diverted substantial capital resources away from productive uses. Those firms which found cotton dust improvements flowing from investments which they intended to make anyway, achieved their expected productivity increases without much economic impact due to OSHA. Those companies which were spurred into more comprehensive and/or speedier modernization, because they saw it as their best solution for compliance with OSHA, probably have had both the largest economic burdens and the largest economic gains in the industry.

To the extent that the technology-forcing aspects of the OSHA cotton dust standard encouraged and intensified the move of textile companies toward automatic openers, chute-fed cards, open-end spinning,

Table 9

U.S. Domestic Cotton Consumption
Million Bales
1976-1983

	Domestic Consumption
1976/77	6.7
1977/78	6.5
1978/79	6.4
1979/80	6.5
1980/81	5.9
1981/82	5.3
1982/83	5.6

Source: National Cotton Council, 1982

shuttleless weaving, automatic cleaners, etc.; more than the health of U.S. textile workers benefited. The health of the U.S. textile industry, and hopefully the future health of the U.S. textile machinery industry have benefited as well.

Technology-forcing aspects of the cotton dust regulation have been acknowledged by government study. A lengthy Department of Commerce study found:

> "The U.S. Occupational Safety and Health Administration dust regulations have had a dramatic effect on short staple processing equipment design and purchasing. Machine suppliers modified equipment to comply with OSHA regulations and this equipment has been accepted on a worldwide basis as well as in the USA. The dust controls have also contributed to much better operating results..."[176]

The British Economist magazine in December 1980, in discussing the comeback of the U.S. textile industry, claimed that:

> "Tougher government regulations on workers' health have, unexpectedly, given the industry a leg up. Tighter dust control rules for cotton plants caused firms to throw out tonnes of old inefficient machinery and to replace it with the latest available from the world's leading textile machinery firms..."

It is just possible that the OSHA cotton dust regulation occurred at a good time in the process of textile industry modernization. Many elements of machine design which could aid in solving problems of OSHA compliance were recognized, and incorporated into new equipment. Of all modes of compliance, designed-in engineering controls are the most effective and the most efficient. While the OSHA cotton dust regulation may have seemed costly in the short run, by coinciding with major technological transformation, it may also have been a hidden blessing by contributing to the increased pace and intensity of modernization in the U.S. textile industry.

FOOTNOTES

[1] American Textile Manufacturer's Institute (ATMI), Tax Committee, Technological Obsolescence in the Textile Industry, Subcommittee on Technological Obsolescence, August 1974.

[2] Centaur Associates, Inc., for OSHA, "Technical and Economic Analysis of Regulating Occupational Exposure to Cotton Dust," Volume I, January 1983, p. 3-8.

[3] Research Triangle Institute (RTI) Study prepared for the Occupational Safety and Health Administration, Department of Labor, 1976, pp. A-6, A-9.

[4] Ibid., p. A-9.

[5] Enviro Control, Inc., for NIOSH. "Control Technology Assessment of Raw Cotton Processing Operations." (NTIS), June 15, 1980, p. 148.

[6] Ibid., p. 156.

[7] C.O. Graham, Jr., et al, "Factors Influencing Dust Levels During Cotton Processing," Southern Regional Research Laboratory (SRRL), U.S. Department of Agriculture, Transaction of the National Conference on Cotton Dust and Health, Charlotte, North Carolina, May 2, 1970, p. 50.

[8] John C. Brooks, Testimony before the Subcommittee on Oversight and Investigations, House Committee on Science and Technology, U.S. Congress, September 22, 1982, p. 4.

[9] ATMI Tax Committee, Technological Obsolesence in the Textile Industry p. 4; RTI Study, p. 20; Graham, p. 50.

[10] U.S. Department of Labor, Report to Congress, Cotton Dust: Review of Alternative Technical Standards and Control Technologies, May 14, 1979, p. 18.

[11] National Institute for Occupational Safety and Health (NIOSH), Occupational Exposure to Cotton Dust, 1974, p. 17.

[12] ATMI Tax Committee, Technological Obsolesence in the Textile Industry, pp. 3-4.

[13] Graham, p. 50.

[14] Research Triangle Institute Study, p. A-20.

[15] NIOSH, Occupational Exporure to Cotton Dust, p. 18.

[16] Dan S. Hamby, ed., The American Cotton Handbook, 3rd Ed. New York: Interscience Publishers, 1965.

[17] Statement of Hovan Hocutt, Senior Vice President, Engineering, Pneumafil Corporation before the public hearing concerning the proposed changes in the OSHA Cotton Dust Standard, 1977, p. 7.

[18] Enviro Control...p. 184.

[19] NIOSH, Occupational Exposure to Cotton Dust, pp. 18 and 19.

[20] Centaur, Volume I ..., p. 3-10.

[21] Enviro Control...p. 203.

[22] Graham, p. 51; NIOSH, Occupational Exposure to Cotton Dust, p. 20; RTI, p. A-35.

[23] NIOSH, Occupational Exposure to Cotton Dust, p. 20.

[24] Graham, p. 51.

[25] RTI Study, p. A-36.

[26] Brooks. Testimony ..., September 22, 1982, p. 4.

[27] The American Cotton Handbook, p. 374.

[28] Centaur, Volume I ..., p. 3-48.

[29] ATMI Tax Committee, Technological Obsolescence in the Textile Industry, p. 16.

[30] "OE Floods the Mills," America's Textiles Reporter/Bulletin, June, 1973, p. 10.

[31] Enviro Control, p. 210.

[32] Centaur, Volume I ..., pp. 3-63, 3-65.

[33] Ibid.

[34] NIOSH, Occupational Exposure to Cotton Dust, p. 21.

[35] RTI Study, p. A-41.

[36] Ibid., p. A-42.

[37] Graham, p. 52.

[38] Brooks. Testimony ..., September 22, 1982, p. 5.

[39] NIOSH, *Occupational Exposure to Cotton Dust*, p. 21.

[40] Enviro Control, ..., p. 261.

[41] R.S.F. Schilling, J.P.W. Hughes, and Fordyce I. Dingwall, "Disagreement Between Observers in an Epidemiological Study of Respiratory Disease," in *British Medical Journal*, I, 1955 pp. 65-68

[42] R.S.F. Schilling, E.C. Vigliani, B. Lammers, F. Valic, and J.C. Gilson, "A Report on a Conference on Byssinosis," in *Proceedings* of the XIVth Int. Congress. Occupational Health, Madrid. (Excerpta Medica: Amsterdam), 1963, pp. 37-45.

[43] B. Ramazzini, *Diseases of Workers, DeMorbs Artificum of 1713*, W.C. Wright (trans.), (Hafner Publishing Co: New York), 1964.

[44] NIOSH, *Occupational Exposure to Cotton Dust*, pp. 22-28.

[45] A. Bouhuys, Presentation at 16th International Conference on Occupational Health, Tokyo, 1969.

[46] NIOSH, *Occupational Exposure to Cotton Dust*.

[47] *Federal Register*, Vol. 43, No. 122, part III, June 23, 1978, p. 27351.

[48] Ibid., p. 27352.

[49] *Federal Register* ..., p. 27352.

[50] Ibid., p. 27354.

[51] U.S. Department of Labor, *Report to Congress*... p. 15.

[52] NIOSH, pp. 43-44.

[53] *Federal Register*, ... p. 27355.

[54] U.S. Department of Labor, *Report to Congress*,... p. A-6.

[55] *Federal Register* ..., p. 27355.

[56] Ibid.

[57] NIOSH, Occupational Exposure to Cotton Dust, p. 149.

[58] Federal Register ..., p. 27358.

[59] Ibid., p. 27358.

[60] Ibid., p. 27380.

[61] Ibid., p. 27360.

[62] Ibid., p. 27361.

[63] Estimates by Society of the Plastics Community and Industrial Research of the Wharton School, University of Pennsylvania. See Chemical Week, May 17, 1975, p. 49 and Herbert Northrup, et al, The Impact of OSHA. (University of Pennsylvania Press: Philadelphia), 1978, p. 305.

[64] See Ruth Ruttenberg, (Ph.D. Dissertation, University of Pennsylvania), 1981.

[65] Brief for the Secretary of Labor, U. S. Department of Labor, "On Consolidated Petitions to Review the Secretary's Occupational Health Standard for Lead in the United States Court of Appeals for the District of Columbia Circuit," No. 79-1048 and consolidated cases, 1979, p. 165.

[66] AFL-CIO v. Brennan, 530 F.2d 109, 121 (3rd Circuit, 1975).

[67] American Iron and Steel Institute v. OSHA.

[68] Society of the Plastic Industries, Inc. v. OSHA, 509 F.2d 1301 (2d Circuit), cert. denied, 421 U.S. 992/1975.

[69] Federal Register ..., p. 27362.

[70] RTI Study ..., 1976, p. IV-7.

[71] Ibid., p. IV-8.

[72] "Statement of the Amalgamated Clothing and Textile Workers Union, AFL-CIO to the Occupational Safety and Health Administration, Volume I," U.S. Department of Labor, Washington, D.C., April 5, 1977, p. 16.

[73] Federal Register ..., p. 27362.

[74] Ibid.

[75] Ibid.

[76] Centaur, Volume I, ..., p. 4-18.

[77] Quoted from ATMI brief in Case No. 78-1562, p. 59 by Amalgamated Clothing and Textile Workers Union, "The Economic Impact of the OSHA Cotton Dust Standard," March 1983, p. 1.

[78] Federal Register, ..., p. 27380.

[79] Ibid., p. 27369; prices assumed to be 1978 dollars since this was the year of publication but may be based on their consultant's 1974 data.

[80] Centaur, Volume II, ..., p. F-38.

[81] Centaur, Volume I, p. 3-35.

[82] Ibid., pp. I-4, 5.

[83] U.S. Department of Commerce, "Opportunities and Strategies for U.S. Textile Machinery Manufacturers to Improve Their Competitive Positions in Domestic and Foreign Textile Markets, 1980-1985," September 1980.

[84] Jordan Yale, "The Economic Structure of the Textile Industry" in Modern Textiles, April 1977, p. 23.

[85] John C. Lumsden, Testimony before Subcommittee on Investigations and Oversight, House Committee on Science and Technology, U.S. Congress, September 22, 1982, p. 7.

[86] Brooks, Testimony ..., September 22, 1982, p. 4.

[87] Ibid.

[88] U.S. Department of Commerce, "Opportunities and Strategies ..."

[89] Federal Register, ..., p. 27366.

[90] Ibid., p. 37367.

[91] Letter to author from John M. Spearman, Area Sales Manager, Omintex, Charlotte, North Carolina, October 5, 1982.

[92] Bulletin of Industrial Hygiene Institute, Winter 1981/82.

[93] Letter from Samuel Lunt, Jr., President, Santek, Inc. to Secretary of Energy, James Edwards, January 27, 1981.

[94] Daily News Record, September 7, 1982.

[95] *Textile World*, September 1981, p. 76.

[96] *Textile World*, September 1981, p. 81.

[97] *Textile Week*, May 10, 1982, p. 5.

[98] U. S. Department of Commerce, Business Conditions *Digest*, November 6, 1981, p. 9.

[99] *Textile Week*, August 17, 1981, p. 2.

[100] Leesona Corporation Press Release, "Leesona Introduces Its New Loom Conversion Unit," September 8, 1981.

[101] *Textile Week*, September 21, 1981, p. 2.

[102] Leesona Textile Division, "New Air System for Filling Insertion Skirts Major Capitol Outlays, Advances Technology," 090881/LCAAWWPY, 1981.

[103] *Textile Week*, September 21, 1981, p. 2.

[104] Daily News *Record*, May 3, 1982, p. 11.

[105] S. Hudak and P. Bohnslav, U.S. Department of Treasury, Office of Industrial Economics, "Supplement: The Textile Industry, A Study of Capital Investment, Technology and Other Factors Affecting Prescribed Capital Recovery Allowances of Textile Machinery," February 1976.

[106] Burlington Industries, Annual Report, 1981, p. 2.

[107] *Textile World*, September 1981, p. 58.

[108] *Textile Week*, April 6, 1981, p. 2 and June 21, 1982, p. 1.

[109] *Textile Week*, August 10, 1981, p. 6.

[110] *Textile Week*, June 28, 1982, p. 5.

[111] *Textile Week*, June 28, 1982, p. 6.

[112] *Textile Industries*, May 1982, p. 59.

[113] Cone Mills, Annual Report, 1981, p. 9.

[114] *Textile Industries*, May 1982, p. 40.

[115] Charlotte *Observer*, February 3-10, 1980, p. 5.

[116] *Textile Week*, June 8, 1981, p. 6.

[117] *Textile Week*, June 16, 1980, p. 6.

[118] *Textile World*, September 1981, p. 62.

[119] Ibid., p. 72.

[120] *Textile Week*, June 15, 1981, p. 5.

[121] Testimony of James Chapman, Jr., President and Treasurer, Inman Mills, OSHA Rulemaking Hearings On Proposed Change in the Cotton Dust Standard, May 1977, Exhibit No. 64.

[122] Charlotte *Observer*, February 3-10, 1980, p. 8.

[123] *Textile World*, September 8, 1982, p. 76.

[124] *Textile Week*, April 6, 1981, p. 5.

[125] *Textile World*, September 1981, p. 81.

[126] Ibid., p. 76

[127] Riegel, Annual Report, 1981, p. 4.

[128] *Textile Week*, December 14, 1981, p. 1.

[129] *Textile Week*, March 10, 1981, p. 5.

[130] *Textile World*, September 1981, p. 70.

[131] Charlotte *Observer*, February 3-10, 1980.

[132] *Textile World*, May 1977, pp. 80-81.

[133] *Textile Week*, March 9, 1981, pp. 1-2.

[134] Stevens Company, Annual Report, 1981, p. 4.

[135] *Textile World*, September 1981, p. 65.

[136] American Textile Manufacturers Institute, reported by the New York *Times*, May 10, 1981.

[137] Rockwell International, Draper Division, "International Textile Machinery Trade Competitive Barriers Confronting The U. S.," January 2, 1974.

[138] U. S. Department of Commerce, U. S. Industrial Outlook, 1982, pp. 205-200.

[139] American Textile Machinery Association, 1982-83 Official Directory, p. 6.

[140] U. S. Department of Commerce. "Opportunities and Strategies...," p. I-47.

[141] American Textile Machinery Association, Textile Machinery Statistics, October 1981, p. 6.

[142] Textile Week, April 7, 1980.

[143] Textile Week, June 15, 1981, p. 6.

[144] Ibid.

[145] Textile Week, April 20, 1981.

[146] U. S. Department of Commerce, Industrial Outlook, 1982, p. 206.

[147] Value Line Industry Survey (Arnold Bernhard & Co.: New York), June 11, 1982, p. 1627.

[148] Value Line Industry Survey, p. 1641.

[149] Stevens Company, Annual Report, 1981, p. 4.

[150] Fritsch, John, (ATMI), Interview, September 1, 1982.

[151] Textile Industries, May 1982, p. 46.

[152] Reist, Parker, Kornreich, Lawrence, Bolda, David, "The Impact of New Production Equipment on Control Costs to Meet the Proposed Cotton Dust Standard," OSHA Hearings, May 2, 1977.

[153] American Textile Machinery Association. Testimony Before Subcommittee on Investigations and Oversight, House Committee on Science and Technology, U.S. Congress, September 22, 1982.

[154] American Textile Machinery Association for the U.S. Department of Energy "Assessment of Energy Conservation Potential at ATME-I 80 Textile Machinery Show in Greenville, S.C., Phase I," December 1980, p. 7.

[155] Ibid.

[156] Textile Week, August 11, 1980.

[157] Daily News Record, September 7, 1982.

[158] U.S. Department of Commerce, "Opportunities and Strategies...," p. II-57.

[159] Textile World, September 1981, p. 81.

[160] Springs Industries, Annual Report, 1981.

[161] Textile Week, May 3, 1982, p. 5.

[162] Seidel, Leon "Projectile Weaving Machines: A Post-Transitional View" in Textile Industries, May 1982, p. 59.

[163] Textile World, September 1981, p.81.

[164] Ibid., p. 62.

[165] Centaur, Volume I ..., p. 5-16.

[166] Ibid., p. 5-24.

[167] Ibid., p. 5-22.

[168] Value Lines Industry Survey, June 11, 1981, p. 1627.

[169] Centaur, Volume I, ..., p. 6-19.

[170] Ibid., p. I-2.

[171] National Cotton Council of America, "Statement of the National Cotton Council of America to the Investigations and Oversight Subcommittee, House Committee on Science and Technology, September 22, 1982, p. 43.

[172] Charlotte Observer, February 3-10, 1980, p. 19.

[173] James Chapman, Jr., Testimony Before OSHA Administrative Law Hearings ...

[174] Letter to author from Howell to Ruttenberg, October 1, 1982.

[175] Centaur, Volume I ..., p. 6-16.

[176] U. S. Department of Commerce, "Opportunities and Strategies..."

Appendix

GLOSSARY

Airborne respirable dust - Fraction of total dust which passes through a selector with specified characteristics closely resembling those of the human respiratory tract.

Autoleveller - Measures automatically the thickness of ingoing material and then adjusts the rollers of the drawing machine so that a constant weight per unit length of sliver is delivered.

Bobbin - A tube usually made from wood, plastic or fiberboard on which yarn is wound after spinning or twisting.

Bract - The leaflike part of the cotton plant directly below the white, downy fiber.

Calender rolls - Rollers which compress the lap or sliver.

Carding - The process in yarn manufacture in which the fibers are brushed up, made more or less parallel, have considerable portions of foreign matter removed, and are put in a manageable form known as sliver.

Chute-fed cards - The pneumatic transport of cotton from cleaning through carding.

Clothing, Card - Rollers or flats that are clothed with fine, cylindrical pressed steel wire, and do carding.

Combing - Removal of all fibers below a certain staple length; i.e., shorter length fibers; and setting them in a uniform, parallel order ready for further manipulation.

Condenser - A delivery section on a card in the woolen system. It splits the doffer web into approximately 60 to 200 strips, condenses them into ropings and winds them on a jack spool.

Cotton dust - Dust present during the handling or processing of cotton which may contain a mixture of substances including ground-up plant matter, fiber bacteria fungi, soil, pesticides, noncotton plant matter and other contaminants which may have accumulated during the growing, harvesting and subsequent processing or storage periods.

Crush rolls - Smooth steel rolls, subjected to adjustable high pressures through which the card web leaving the doffer is passed in full width.

Delintering - The process of separating the very short, coarse linter fibers from cottonseed.

Doffing - Stripping the sliver from the carding machine.

Drawing - The process of combining individual ends of sliver (usually 6 to 8) and drafting them to a lower, specified weight per unit length (i.e., grains per yard).

End - A warp yarn or thread that runs lengthwise or vertically in cloth.

Ends down - Warp ends which have broken in weaving, thereby impeding production.

Filet - A knotted square mesh or net.

Filling - In woven fabric, the yarn that is inserted across the loom. Also referred to as weft, or crosswise yarns in the fabric.

Ginning - The process of separating the cottonseed from the lint fiber attached to it during growth.

Lap - Loosely compressed cotton sheets. The card changes a lap into a sliver.

Lap roll - Cotton lap is wound around this roll in the calender section of the picker machine.

Licker-in - A hollow grooved cylinder used in carding; it opens the tufts of cotton held by the feed roll and plate.

Lint - The relatively long, workable cotton fiber which can be used in yarn manufacture.

Linters - The short (less than 1/4") fuzzy fiber which still covers the cottonseed after the lint fiber is removed (ginned).

Lint-free cotton dust - Dust less than 15 micrometers (15 um) aerodynamic diameters.

Opener picker - An auxiliary cleaning machine used when high-quality cotton yarn is desired.

Opening - The initial treatment of raw cotton; the separation and opening up of the cotton to remove compression because of baling and shipping. Heavier impurities are also removed from the stock. Opening is concluded when the cotton lap is made ready for actual carding.

PEL - Permissible exposure limits.

Pick - One passage or throw of the shuttle of a loom; one of the weft threads, or filling yarns; to throw (a shuttle).

Picker lap - The lap or web obtained as the cotton comes from the finisher picker machine.

Picking - Continuation of the opening process which casts out the heavier wastes in cleaning the stock; the process in yarn manufacture of cleaning the fiber and forming it into a sheet which is compressed and wound on a cylindrical roll.

Quilling - The last process in preparing filling yarns for weaving; winding the yarn or filling bobbins (quills) ready for insertion into the shuttle.

Roving - The last process before spinning in which the soft strand of sliver is drafted and twisted sufficiently to hold it together during spinning. Also referred to as the strand of fiber produced by the process.

Selvage (Selvedge) - A narrow woven edge portion of fabric parallel to the warp, made with special stronger yarns.

Slashing - The sizing of warp yarns to protect the yarns against injury during weaving.

Sliver - The loose, thin continuous rope-like soft strand of parallel fibers which is the product from carding, combing and drawing, and which is ready for drawing and twisting.

Spinning - The final process in forming yarn in which the soft roving strand is drafted by a series of rollers and twisted to provide strength.

Spooling - Winding yarns on spools.

TLV - Threshold limit value.

Total airborne dust - All dust collected during sampling without selector.

Twisting - The act of turning a strand of parallel fibers on itself to provide the necessary strength to hold it together. Also the process of combining two or more strands of yarn into a single strand.

Vertical elutriator cotton dust sampler - A dust sampler which has a particle size cut-off at approximately 15 microns aerodynamic equivalent diameter when operating at the flow rate of 7.4 ± 0.2 liters per minute.

Warp - The threads running lengthwise in the loom and crossed by the weft.

Warping - The process in which several hundred individual strands of yarn are formed into a parallel sheet and wound onto a special beam for slashing or dyeing.

Weaving - Interlacing two yarns so they cross each other at right angles to produce woven fabric.

Web - The structural part of cloth as distinguished from the pattern effect in it.

Weft - (Sometimes called woof or filling.) The yarns carried by the shuttle back and forth across the warp in weaving.

Winding - A process of transferring yarn or thread from one type of package to another; e.g., from bobbins to tubes.